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Gary L. DeBarr · Edward P. Merkel

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MIST BLOWER SPRAYING OF LONGLEAF PINE FOR CONE AND SEED INSECT CONTROL

by

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In the past, longleaf pine, *Pinus palustris* Mill., has received little emphasis in the establishment of pine seed orchards in the southern United States. Recently, however, tree improvement programs have revived interest in this commercially important species. Consequently, we can expect seed orchard acreages of longleaf pine to expand noticeably in the future. This trend will undoubtedly be attended by an increased urgency to protect longleaf pine seed from destructive insects.

Wakeley (1931) reported damage by a coneworm, *Dioryctria amatella* Hulst, on longleaf pine. Wahlenberg (1946) also observed *D. amatella* cone damage in several southern states; in addition, he found cone damage caused by *D. abietella* (D. & S.). In Mississippi, conelet losses as high as 90 percent were primarily the result of *D. amatella* mining in twig terminals (Coyne and Allen 1956), whereas Shoulders (1968) found female strobili losses of 70 percent due to "insects and other agents" in a longleaf stand in Louisiana. Ebel (1963) summarized the insects known to affect longleaf pine seed production, and later studied the role of a beetle, *Ernobius granulatus* LeConte, in relation to longleaf conelet abortion, concluding that the beetle was a secondary invader of dead and dying conelets (Ebel 1964). Coyne (1968) reported that a seedworm, *Laspeyresia ingens* Heinrich, destroyed an average of 21 percent of the annual longleaf seed crop produced in the gulf coast region of the United States.

In early tests conducted at the Southern Institute of Forest Genetics, four bimonthly hydraulic sprayer applications of benzene hexachloride (BHC), beginning in March or April, increased first-year cone survival of longleaf pine (Allen and Coyne 1956; Coyne 1957). Merkel and Yandle (1965) reported that cone and seed losses caused by *Dioryctria* spp. were reduced by spraying slash pines with three mist blower applications of a 2.5 percent BHC or 1.0 percent azinphosmethyl (Guthion®) water emulsion. A single azinphosmethyl application controlled the slash pine seedworm, *L. anaranjada* Miller, whereas hydraulic sprayer or mist blower sprays of BHC were unsuccess-

ful. Later, Merkel (1968) found that a wetting spray of fenthion reduced *L. ananranjada* infestation in slash pine cones.

Numerous experiments (Buffam and Johnson 1966; Hedlin 1964, 1966; Johnson 1963; Johnson and Hedlin 1967; Johnson and Meso 1966; Johnson and Rediske 1964, 1965) in Washington State and British Columbia have shown that dimethoate, when used to thoroughly wet the foliage, is an effective systemic insecticide for the control of most insects infesting the cones of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco. Prior successes with dimethoate for the control of Douglas-fir cone and seed insects prompted us to conduct experiments in north Florida during 1966 and 1967 to evaluate this, along with several other promising insecticides for control of *Dioryctria* spp. and *Laspeyresia ingens* infesting longleaf pine cones.

MATERIALS AND METHODS

The experiments described in this paper were conducted during 1966-1968 on large, open-grown longleaf pines along a highway right-of-way in Columbia County, in northeast Florida. The trees were originally part of a natural stand of 48-year-old longleaf. They averaged 55 feet tall and 14 inches d.b.h. All the applications were made with a tractor-drawn John Bean Model 100F "Rotomist" mist blower nozzled to deliver 1.25 gallons per minute while operating at 300 p.s.i. pressure (fig. 1). In seed orchards, mist blowers are usually operated at a continuous slow speed (DeBarr and Merkel 1969); but since the trees we sprayed were not evenly spaced in rows, we stopped the mist blower on opposite sides of each tree in order to deliver the desired volume of material. The insecticides were applied shortly after sunrise, or before sunset, when wind conditions were the most ideal for thorough spray droplet distribution.

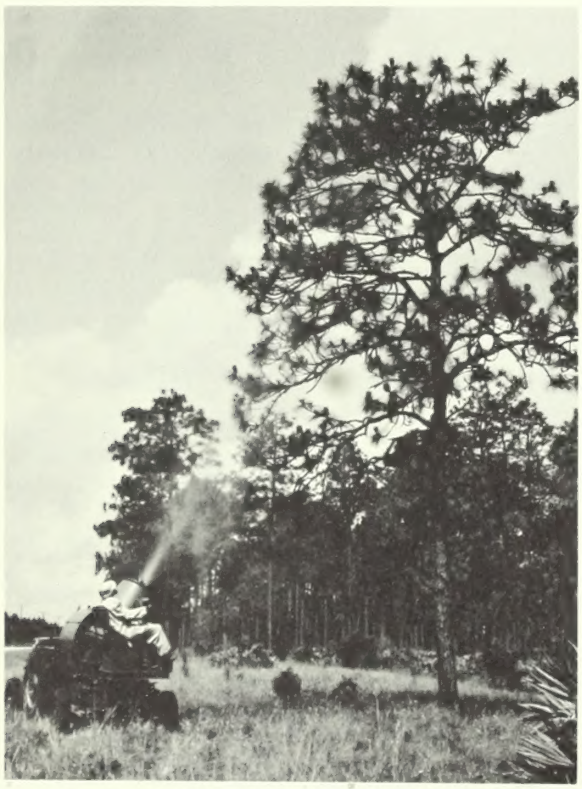

Figure 1.—Mist blower sprays longleaf pine for coneworm and seedworm control.

Water emulsions of the following materials were used in the spray tests on longleaf pine: (1) BHC liquid emulsifiable concentrate containing 1.0 pound of benzene hexachloride[1] gamma isomer per gallon of concentrate; (2) Guthion® emulsifiable concentrate containing 2 pounds actual azinphosmethyl[2] per gallon of concentrate; (3) Cygon® 267 containing 2.67 pounds of actual dimethoate[3] per gallon of concentrate; and (4) Bayer 29493 emulsifiable concentrate containing 4 pounds of actual fenthion[4] per gallon of concentrate (table 1).

Control of *Dioryctria* coneworms was evaluated at cone harvest by determining the proportion of the total number of second-year cones per tree which had been successfully attacked by larvae. In addition, for some tests coneworm attacks on both first- and second-year cones were recorded on 20 sample branches per tree in midsummer.

Effect of treatments against *Laspeyresia ingens* on longleaf pine was evaluated on the basis of the proportion of second-year cones infested in a 50-cone sample per tree. During the winter the samples were bisected with a table model cone cutter (DeBarr and Proveaux 1969) to expose overwintering larvae in the cone axis.

[1] (1,2,3,4,5,6 -hexachlorocyclohexane, mixed isomers).

[2] *O,O*-dimethyl *S*-4-oxo-1,2,3-benzotriazin-3 (4*H*)-ylmethyl phosphorodithioate.

[3] *O,O*-dimethyl *S*-(*N*-methylcarbamolymethyl) phosphorodithioate.

[4] *O,O*-dimethyl *O*-[4-(methylthio)-*m*-tolyl] phosphorothioate.

Table 1.—1966-1968 mist blower treatments for cone and seed insect control on longleaf pine, Columbia County, Florida

Test No.	Insecticide and concentration[1]	Application		Volume spray per tree	Active ingredient per:	
					Tree	Acre[2]
		No.	*Date*	*Gallons*	*- - Pounds - -*	
1	dimethoate (2.5%)	3	4/6[3]; 4/22;5/20/1966	1.3	0.28	13.3
	dimethoate (1.25%)	1	6/28/1966	1.3	.14	6.65
2	dimethoate (1.25%)	3	4/18; 6/13;7/6/1967	2.0	.21	10.0
3	fenthion (2.0%)	3	4/17; 6/14; 7/20/1967	2.0	.34	16.3
4	BHC (2.5%)	3	4/13; 5/16; 6/13/1968	2.0	.43	27.4
5	azinphosmethyl (1.0%)	3	4/12; 5/15; 6/14/1968	2.0	.17	7.76

[1]Percent concentration by weight of active toxicant.
[2]Based upon 48 trees/acre (30- by 30-foot spacing).
[3]Plyac® spreader-sticker added—2 pints/100 gallons.

RESULTS

***Dioryctria* control on first-year cones.**—*Dioryctria*-caused conelet mortality and the incidence of conelet abortion due to unknown causes were recorded only in tests 1, 2, and 3 (table 2). Three applications of 1.25 percent dimethoate reduced (94 percent) *Dioryctria* attacks significantly on first-year cones. In test 1, dimethoate was applied four times and at twice the amount of toxicant per tree as in test 2, but it failed to protect conelets from coneworm attack. Three applications of 2.0 percent fenthion did not reduce coneworm-caused conelet losses.

Aborted conelets on unsprayed trees averaged 20 percent in 1966 and 35 percent in 1967, and no significant reduction in abortion was detected on dimethoate- and fenthion-sprayed trees in either year (table 2).

***Dioryctria* control on second-year cones.**—The prevention of successful coneworm attacks on maturing cones is summarized in table 3. The incidence of coneworm infestation at midsummer was recorded only in the tests with dimethoate and fenthion. These insecticides reduced attacks through June, but control was not adequate, since little or no cone protection was afforded by the dimethoate and fenthion treatments from early July until cone harvest. However, BHC and azinphosmethyl significantly reduced cone infestation by 56- and 94-percent, respectively, for the entire summer (table 3).

Control of *Laspeyresia ingens* on second-year cones.—The results of all tests on the control of *L. ingens* are summarized in table 4. Of the four insecticides evaluated, only azinphosmethyl significantly reduced the numbers of infested cones. When compared with unsprayed checks, azinphosmethyl-sprayed trees had 88 percent fewer seedworm-infested cones. In addition, check trees had an average of 0.6 larva per cone, whereas cones from trees sprayed with azinphosmethyl averaged only 0.07 larva per cone (fig. 2).

Table 2.—First-year longleaf pine conelet abortion and infestation by *Dioryctria* spp. Mist blower treatments, Columbia County, Florida

Test No.	Insecticide	Observation date	Total conelets examined[1]	Conelet abortion[2]		Mean *Dioryctria* infestation per tree[3]		Reduction
				Checks	Sprays	Checks	Sprays	
			Number	*Percent*		*Percent*		*Percent*
1	dimethoate	6/15/1966	686	--	--	6.7	8.2	0
		11/1/1966	686	20.4	26.2	10.6	12.0	0
2	dimethoate	7/1/1967	883	34.9	33.8	2.7	.16	94*
3	fenthion	7/1/1967	893	34.9	44.5	2.7	5.5	0

[1]Based upon observations on conelets on a 20-branch/tree sample.
[2]Conelets dead from unknown cause(s).
[3]Eight or more trees (replicates) per treatment.
* = t-test of the difference between check and spray means significant (P = 0.05).

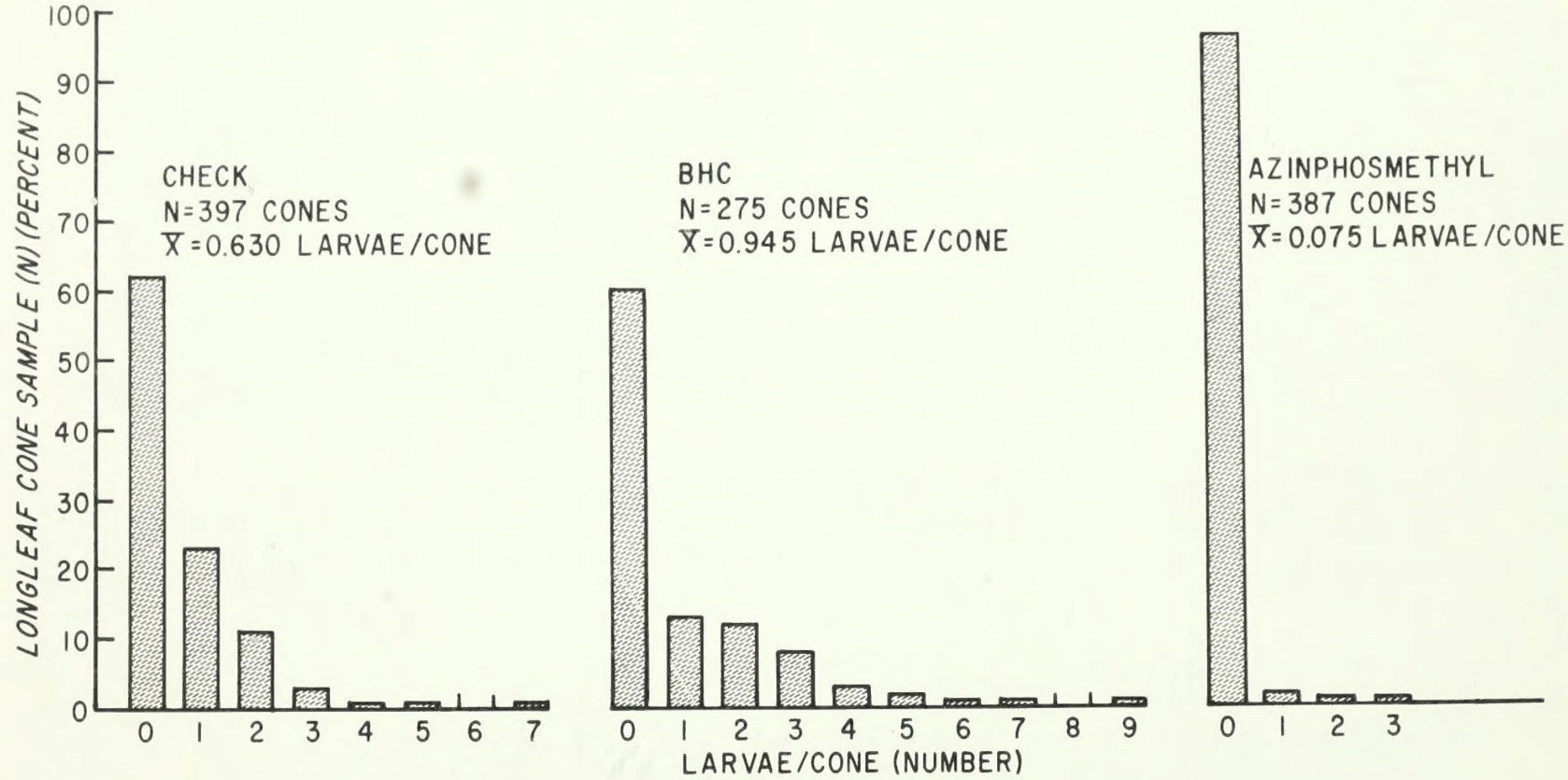

Figure 2.—Comparison of treatment effects on the incidence of larval infestation by *Laspeyresia ingens* in tests 4 and 5.

Table 3.—Second-year longleaf pine cone infestation by *Dioryctria* spp. Mist blower treatments, Columbia County, Florida

Test No.	Insecticide	Observation date	Total cones examined	Mean infestation per tree[1]		Reduction in cones infested
				Checks	Sprays	
			Number	*Percent*		*Percent*
1	dimethoate	6/15/66	[2]291	2.6	1.4	46 NS
		11/1/66	[2]291	46.0	29.7	35 NS
2	dimethoate	7/1/67	[2]534	14.2	8.3	41.5 NS
		11/1/67	[3]2,741	12.7	14.5	0 NS
3	fenthion	7/1/67	[2]712	14.2	8.1	43 NS
		11/1/67	[3]3,300	12.7	12.9	0 NS
4	benzene hexachloride	11/1/68	[3]1,544	16.6	7.3	56**
5	azinphosmethyl	11/1/68	[3]2,892	16.6	1.0	94**

[1]Eight or more trees (replicates) per treatment.
[2]Observations on cones on a 20-branch/tree sample.
[3]100% tally of mature cone crop on each tree.
** = t-test of the difference between check and spray means highly significant (P = 0.01).

Table 4.—*Laspeyresia ingens* infestation in second-year longleaf pine cones. Mist blower treatments, Columbia County, Florida

Test No.	Insecticide	Observation date	Cones bisected[1]	Mean infestation per tree		Reduction in cones infested
				Checks	Sprays	
			Number	*Percent*		*Percent*
1	dimethoate	Fall 1966	80	68.3	46.6	32 NS
2	dimethoate	Fall 1967	649	27.3	21.9	20 NS
3	fenthion	Fall 1967	707	27.3	25.4	7 NS
4	benzene hexachloride	Fall 1968	672	38.6	42.2	0 NS
5	azinphosmethyl	Fall 1968	784	38.6	4.7	88**

[1]If entire mature cone crop per tree was less than 50 cones, all cones were bisected; otherwise, a 50-cone sample was examined.
** = t-test of the difference between check and spray means highly significant (P = 0.01).

DISCUSSION

Four insecticides, dimethoate, fenthion, benzene hexachloride, and azinphosmethyl were tested in order to find an effective and economical insecticide for preventing seed losses in longleaf pine seed orchards. Fenthion did not significantly reduce cone and seed insect infestation. Dimethoate did prevent damage of conelets, but the poor protection of second-year cones from *Dioryctria* spp. and *L. ingens*, along with its high cost (table 5), make mist blower applications of this insecticide uneconomical for longleaf pine cone and seed insect control.

Table 5.—Relative insecticide costs[1] for mist blower applications tested for *Dioryctria* and *Laspeyresia* control on longleaf pine

Test No.	Insecticide	Concentration by weight of active toxicant	Cost/ tree/ application	Cost/ acre/ application	Cost/ tree/ year	Cost/ acre/ year[2]
		Percent	- - - - - - - - - - *Dollars* - - - - - - - - - -			
1	dimethoate	1.25	1.25	60.00	3.75	180.00
2	BHC	2.5	.75	36.00	2.25	108.00
3	azinphosmethyl	1.0	.60	28.00	1.80	84.00

[1]Labor costs excluded.
[2]Based upon 30- by 30-foot spacing (48 trees/acre).

Conelet abortion was not affected by the insecticide treatments, but the data collected during 1966 and 1967 substantiate earlier reports that abortion of first-year longleaf pine conelets represents a serious obstacle to maximizing seed production of this species.

Three applications of 2 gallons of 2.5 percent benzene hexachloride per tree reduced *Dioryctria* spp. damage by 56 percent when compared with the unsprayed check trees. BHC failed to reduce seedworm infestation, just as it failed to control the slash pine seedworm in previous experiments (Merkel and Yandle 1965). Three applications of 2 gallons of 1.0 percent azinphosmethyl per tree caused a reduction of *Dioryctria* spp. infestation of 94 percent, and *Laspeyresia ingens* infestation of 88 percent, when compared with the unsprayed check trees.

The total cost for material and labor for three applications of azinphosmethyl per tree, assuming a labor cost for two men at $2.00 per man-hour would be approximately $1.90 per tree. Therefore, the value of the increased seed yield per tree would have to be equal to, or greater than, $1.90 per tree in order to justify spraying. The longleaf trees we sprayed averaged 135 cones or approximately 1.5 bushels of cones per tree. Sixteen and one-half percent of the longleaf cone crop on the unsprayed trees in our Columbia County, Florida, plots were infested with *Dioryctria* spp. in 1968. These *Dioryctria*-caused seed losses amounted to approximately 0.25 bu. of cones or 0.185 lb. of seed per tree. Azinphosmethyl reduced *Dioryctria* infestation by 94 percent, and produced increased seed yields of 0.174 lb./tree. In addition, the unsprayed trees had an average of 0.63 seedworm larva/cone that caused seed losses of approximately 5 percent, or 0.06 lb. seed/tree. Azinphosmethyl reduced *Laspeyresia ingens* infestation by 88 percent, and thus increased seed yields by 0.053 lb. seed/tree. If a pound of longleaf pine seed from a seed orchard is assumed to be worth $10.00, the value of the increased seed yield due to cone and seed insect control is equal to 0.174 lb. + 0.053 lb. = 0.227 lb. seed/tree × $10.00/lb. = $2.27/tree. These calculations are based upon monetary seed values which we feel would be conservative for orchards of a genetically superior longleaf pine. In addition, the rates of infestation for *Dioryctria* and *Laspeyresia* which we encountered are quite low. Coyne estimated that an average of 21 percent of the annual seed crop was lost to *Laspeyresia* in the Gulf States. Finally, the calculations do not take into account any benefits gained by protecting first-year conelets from insect attacks.

Based upon the results of this study, azinphosmethyl is the most effective and economical (table 5) insecticide of the four we tested for protecting longleaf pine seed from cone and seed insects.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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Fenthion, dimethoate, azinphosmethyl, and BHC were tested. The best control of coneworms and the seedworm was obtained with three monthly sprays (starting in mid-April) of a 1.0 percent water emulsion of azinphosmethyl (Guthion®) at the rate of 2 gallons per tree (7.8 lb. actual azinphosmethyl per acre). These treatments reduced Dioryctria attacks on second-year cones during the period from mid-April to mid-October by 94 percent; infestation by L. ingens was reduced by 88 percent, compared with cones on untreated trees. The estimated cost of the azinphosmethyl treatments was $84 per acre per year; the estimated value of increased seed yield more than offset the cost of treatment.

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Forest Service, U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

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Russell M. Burns · R. H. Brendemuehl

USDA Forest Service Research Paper SE-77 · January 1971

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by

Russell M. Burns, Silviculturist

and

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Marianna, Florida

INTRODUCTION

Each year throughout the South, slash pine (*Pinus elliottii* Engelm.) seedlings are planted by the millions. Planters want stock with a high potential for survival and growth. Satisfying this demand may tax nursery resources and require that quality seedlings be raised in large number on each available foot of nursery soil.

Seedling size often is used as a measure of quality. Experience has shown that large pine seedlings from a given nursery generally survive better and grow faster than smaller ones from the same nursery. The nurseryman's dilemma arises because, within reasonable limits, only a given amount of vegetative material can be produced in any unit area. Many small or fewer large seedlings may be raised in each nursery bed.

Nurserymen, foresters, and land managers might ask: At what density can a maximum number of plantable seedlings be produced without increasing the proportion of cull or spindly seedlings beyond tolerable limits of 15 to 20 percent of total production? What constitutes a plantable seedling? Do Wakeley's[1] morphological grades adequately stratify seedlings as to their performance? Four experiments were conducted to answer these and related questions.

METHODS

In Test 1 (1958) and Test 2 (1959) the effects of seedling grade on field performance were examined. Slash pine seedlings from three Florida Forest Service nurseries were lifted on the first Monday of December, and at 4 biweekly intervals thereafter, for delivery and grading at the planting site the following day. Representative graded samples from each nursery were planted within a few days of lifting.

Test 3 (1958) and Test 4 (1959), conducted concurrently with Tests 1 and 2, compared the morphological grade of seedlings produced at each of four nursery bed densities, and the 5-year field performance of each grade and bed density. Densities

[1]Wakeley, P. C. Planting the southern pines. USDA Forest Serv. Agr. Monogr. 18, 233 pp. 1954.

approximating 10, 20, 30, and 40 (actually 9.2, 20.1, 29.6, and 43.3) seedlings per square foot were used in Test 3. Seedlings for Test 4 were raised at densities aimed at 20, 30, 40, and 50 (actually 20.0, 31.3, 42.6, and 53.3) per square foot. The top-root ratio of representative samples from each grade and nursery bed density was computed from seedling green weights.

Refinements of Wakeley's Morphological Seedling Grades for slash pine were used to thoroughly evaluate differences in field performance by grade (table 1). Modification A was used in Tests 1 and 3, and modification B was used in Tests 2 and 4. Foliar analyses for N, P, and K also were made to determine if differences existed among nurseries, lifting dates within nurseries, and seedling grades. The Kjeldahl method, modified to include nitrates, was used to determine total foliar N. P and K determinations were made of pine needles dry ashed at 490° ± 10° C. for 4 hours and then taken up in 10 ml. of 8 *N* HCl. Foliar P was determined colorimetrically by the vanadate-molybdate procedure utilizing a B & L Spectronic 20 colorimeter. A Beckman DU flame spectrophotometer was used for K determinations.

Table 1.—Essential differences in morphological grading specifications for 1-year-old slash pine seedlings

Grade	Thickness of stem at ground line		
	Wakeley[1]	Modification A	Modification B
	Inch		
1	3/16 or larger	----	3/16 or larger
1A	----	1/4 or larger	----
1B	----	3/16 to 1/4	----
2	1/8 or larger	Less than 3/16	----
2A	----	----	1/8 to 3/16
2B	----	----	Less than 1/8
3	Less than 1/8*†	Less than 3/16*	Less than 3/16*
Cull	Same as grade 3	†	†

[1]Wakeley, P. C. Planting the southern pines. USDA Forest Serv. Agr. Monogr. 18, 233 pp. 1954.

*Essentially no bark, no winter buds, and no fascicled needles.

†Roots less than 5 inches long; serious insect, disease, or mechanical damage.

All experiments were replicated in randomized, complete block designs. Morphologically graded, 1-year-old slash pine seedlings were used throughout the tests, and these were bar-planted at a 3- by 3-foot spacing on cleared sandhills mapped as Lakeland sand. Finally, survival and height growth at plantation age 5 years were analyzed by appropriate statistical procedures. In all, survival and growth of more than 12,000 seedlings were followed for 5 years.

RESULTS

NURSERIES AND SEEDLINGS

The quality and subsequent performance of seedlings used in Tests 1 and 2 varied with the nursery at which they were raised. Seedlings from nursery "A" were comparatively large and had well-developed tops and roots. They had been raised on sandy soil with a hardpan at 22 to 28 inches. Seedlings from nursery "B," grown on droughty, sandy soils underlain by porous limestone, were smaller than those from nursery "A" but were equally well formed. The smallest seedlings were produced at nursery "C." With the exception of those placed in Grade 1, nursery "C" seedlings all had poorly developed lateral roots. They were raised on sandy clay loam soil that had been leveled to facilitate nursery production. The roots of seedlings from nursery "C" seemed dry when delivered on the day after they were lifted, although they left the nursery in well-watered bales.

TIME OF LIFTING AND PLANTING

In Test 1, first-year survival of seedlings from all nurseries was good (71 percent or better) for stock lifted on or after December

16 (Shipments 2, 3, 4, and 5), but averaged less than 43 percent for seedlings lifted on December 2 for Shipment 1 (table 2). By plantation age 5 years, seedlings lifted on December 2 were shorter and their survival was 29 percent lower than the average of those lifted later.

Similar results were obtained in Test 2. First-year survival was excellent (91 percent or better) for seedlings lifted on or after December 29 (Shipments 3, 4, and 5); good (71 percent) for Shipment 1, lifted on December 1; and fair (64 percent) for Shipment 2, lifted on December 15. Subsequent mortality further reduced survival of seedlings in Shipment 1 to 47 percent and in Shipment 2 to 43 percent by plantation age 5 years. In comparison, survival of seedlings in Shipments 3, 4, and 5 was significantly (.01 level) higher (77 percent or better) than earlier shipments. Growth of seedlings in Shipments 2, 3, 4, and 5 was significantly (.01 level) greater than those in Shipment 1.

Analyses of needle samples showed no significant differences in percentage of foliar N, P, or K associated with time of lifting.

Table 2.—The effect of time of lifting and planting on field performance of 1-0 slash pine seedlings

Shipment	Approximate delivery and planting date	Survival				5-year growth	
		Test 1		Test 2			
		1st year	5th year	1st year	5th year	Test 1	Test 2
	Month/Week	*Percent*				*Feet*	
1	Dec. 1	43	31	71	47	3.5	3.0
2	3	80	60	64	43	3.7	3.4
3	5	71	56	91	78	3.8	4.0
4	Jan. 3	76	59	94	77	3.8	3.3
5	5	77	62	98	84	3.9	3.5

Transplanting involved no drastic changes in temperature for the seedlings. Winter temperatures near the planting site (table 3) were slightly lower than those at nurseries "A" and "B," and slightly higher than those at nursery "C." Temperature records suggest that seedlings lifted late in December and in January were more completely dormant than those lifted earlier. Rainfall and temperature records also suggest that soil temperature and soil moisture were more favorable for seedling establishment late in December and in January than in early- and mid-December. Survival and growth data tend to support this observation.

GRADE

Morphological seedling grade significantly (.01 level) affected field performance. Five-year survival and growth were best for high quality seedlings and became progressively poorer with each successive decrease in quality through Grade 3 (fig. 1).

Nonplantable grades were those in which seedlings failed to maintain an arbitrarily set survival of about 60 percent at 5 years. No standard was set for growth because black root rot (a fungal complex of *Sclerotium bataticola* and *Fusarium* species), believed to be endemic in the sandhill soils,

Table 3.—Temperature and rainfall recorded at Blountstown, Florida

Winter	Nov.	Dec.	Jan.	Feb.	March
	Mean temperature (degrees F.)				
1957-58	61.7	51.2	45.0	44.5	58.2
1958-59	61.3	50.4	48.8	58.4	57.5
	Total rainfall (inches)				
1957-58	7.38	1.58	5.13	5.02	7.28
1958-59	4.12	2.37	5.62	5.86	10.21

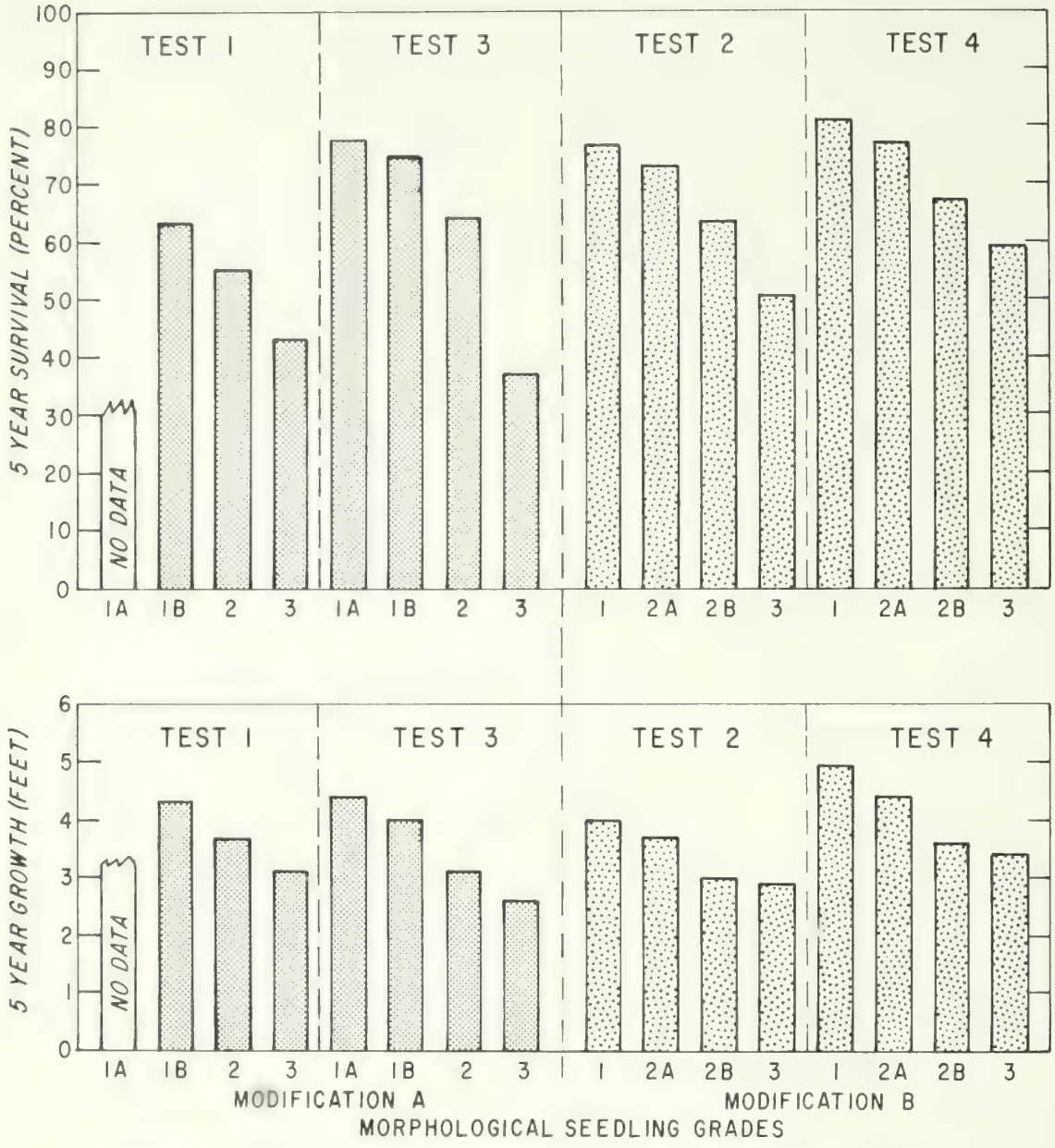

Figure 1.—Fifth-year survival and growth of morphologically graded seedlings.

infected these plantings and retarded growth.

In Tests 1 and 3, survival of Grade 3 seedlings averaged about 40 percent. Grade 2 seedling survival was borderline, averaging 55 percent in Test 1 and 64 percent in Test 3. Considering the refractory nature of sandhills, Grade 2 seedlings were deemed plantable along with Grades 1A (77 percent survival) and 1B (67 percent). The acceptance of Grade 2 seedlings was decided by seedling survival of Grade 2A (75 percent) and Grade 2B (65 percent) in Tests 2 and 4. Survival of Grade 3 averaged 47 percent and, considering results of all the tests, was the only unplantable or cull grade. This agrees with Wakeley's recommendation to cull seedlings below Grade 2.

Quality, as measured by seedling grade, varied considerably among nurseries. Seed-

lings from nursery "A" were large and robust and those from nursery "C" were comparatively small and spindly. Yet, as an example of their overall performance, Grade 3 seedlings from nursery "C" survived and grew taller than Grade 2B seedlings from nursery "A." Seedlings from nursery "B" were intermediate in size and survived and grew best of all. Despite these differences, morphological grading efficiently ranked seedlings as to quality within each nursery.

The level of seedling nutrition (as indicated by foliar N, P, and K) varied by seedling grade, nursery, and year of sampling. Foliar nutrient values for those seedlings from nursery "B" showed the least variation between grades and sampling years. The N content of these seedlings was the highest, with P and K intermediate in the range of values reported (table 4). Seedlings from nursery "B" exhibited the best 5-year field performance; the poorest record was produced by seedlings from nursery "A." Seedlings from nursery "A" had the highest P and greatest variation in foliage N and K contents of the nurseries sampled, suggesting a nitrogen-phosphorus imbalance.

NURSERY BED DENSITY

Density at which seedlings were raised determined the number and influenced the grade of those produced. In itself, bed density had no direct nor consistent effect on field performance and was correlated with survival and growth only through seedling grade. Grade for grade, seedlings from high-density beds survived and grew as well as those from beds of lower density. Density at

Table 4.—Comparison of nutrient content, by nursery and seedling grade

FOLIAR N

Test No.	Nursery	Seedling grade				Average
		1A	1B	2	3	
		Percent of dry foliage weight				
1	A	--*	0.88	0.86	1.09	0.94
	B	--	1.59	1.48	1.62	1.56
	C	--	1.30	1.22	1.38	1.30
		1	2A	2B	3	
2	A	1.46	1.40	1.34	1.68	1.47
	B	1.63	1.54	1.59	1.66	1.60
	C	1.35	1.24	1.14	1.37	1.28

FOLIAR P

		1A	1B	2	3	
1	A	--	.16	.15	.17	.160
	B	--	.13	.13	.14	.133
	C	--	.12	.12	.14	.127
		1	2A	2B	3	
2	A	.16	.17	.15	.17	.162
	B	.12	.12	.13	.14	.128
	C	.09	.10	.10	.12	.102

FOLIAR K

		1A	1B	2	3	
1	A	--	.46	.44	.49	.463
	B	--	.46	.44	.45	.450
	C	--	.50	.49	.52	.503
		1	2A	2B	3	
2	A	.65	.70	.70	.69	.685
	B	.44	.52	.54	.54	.510
	C	.44	.47	.50	.50	.478

*Insufficient foliage for analysis.

which seedlings were grown had virtually no effect on the green weight, top-root ratio. Among plantable Grades 1, 2A, and 2B, however, the balance of tops to roots definitely favored high-grade seedlings at each bed density. Grade 1 seedlings grown at a bed density of 20 seedlings per square foot had a top-root ratio of 3.26, whereas Grade 2B seedlings grown at a density of 50 per square foot had a ratio of 5.35.

Closely grown seedlings tended to be smaller than those grown at wider spacings; consequently, the proportion of large, morphologically high-grade seedlings decreased as bed density increased. In Test 3, more Grade 1A and Grade 1B seedlings were produced with each increase in bed density, but they formed proportionately less of total production (table 5). At a density of 43.3 seedlings per square foot, more Grade 2 seedlings were produced than Grades 1A and 1B combined. Concomitant with the proportionate decrease in high-grade seedlings was an increase in the proportion of culls and Grade 3 seedlings (deemed unplantable as the result of their field performance and hereafter regrouped as culls). Culls comprised almost 21 percent of total production at the highest bed density of Test 3.

In Test 4, the total number of seedlings in Grades 1 and 2A declined between bed densities of 42.6 and 53.3 per square foot while those of Grade 2B and cull stock continued to increase. Culls made up more than 21 percent of total production at bed density 53.3.

Many nurseries consider a 15- to 20-percent loss to all causes as a maximum allowable cull factor. Thus, optimum numbers of slash pine can be raised at the highest density from which no more than one-fifth of the seedlings must be discarded as "unplantable." To obtain an estimate of "optimum bed density" for slash pine seedlings, regression analyses were made of the proportion of cull seedlings at each bed density, using data from Tests 3 and 4. Results suggest that optimum numbers of plantable seedlings can be produced at densities averaging 40 to 45 seedlings per square foot (fig. 2).

SUMMARY AND CONCLUSIONS

The effects of nursery bed density on morphological seedling grade and the effects of seedling grade on 5-year survival and growth were examined for 1-0 slash pines planted on infertile, droughty sandhills in west Florida. Supplemental to the interpretation of results were comparisons of lifting dates at three nurseries, green weight top-root ratios, and analyses of foliage for N, P, and K.

Morphologically high-grade seedlings survived and grew significantly (.01 level) better than those of lower grades. The poor field performance of Grade 3 seedlings confirmed Wakeley's contention that this grade

Table 5.—Proportionate distribution of seedlings by grade and normal bed density

TEST 3

Grade	Seedlings per square foot (aimed for/actual)			
	10/9.2	20/20.1	30/29.6	40/43.3
	Percent			
1A	41.7	11.8	6.0	5.1
1B	41.1	35.6	24.6	18.3
2	11.3	43.6	57.2	56.1
Culls	5.9	9.0	12.2	20.5
Total	100.0	100.0	100.0	100.0

TEST 4

	20/20.0	30/31.3	40/42.6	50/53.3
1	43.8	25.6	18.1	13.7
2A	40.3	40.2	31.8	23.6
2B	9.7	24.1	35.1	41.1
Culls	6.2	10.1	15.0	21.6
Total	100.0	100.0	100.0	100.0

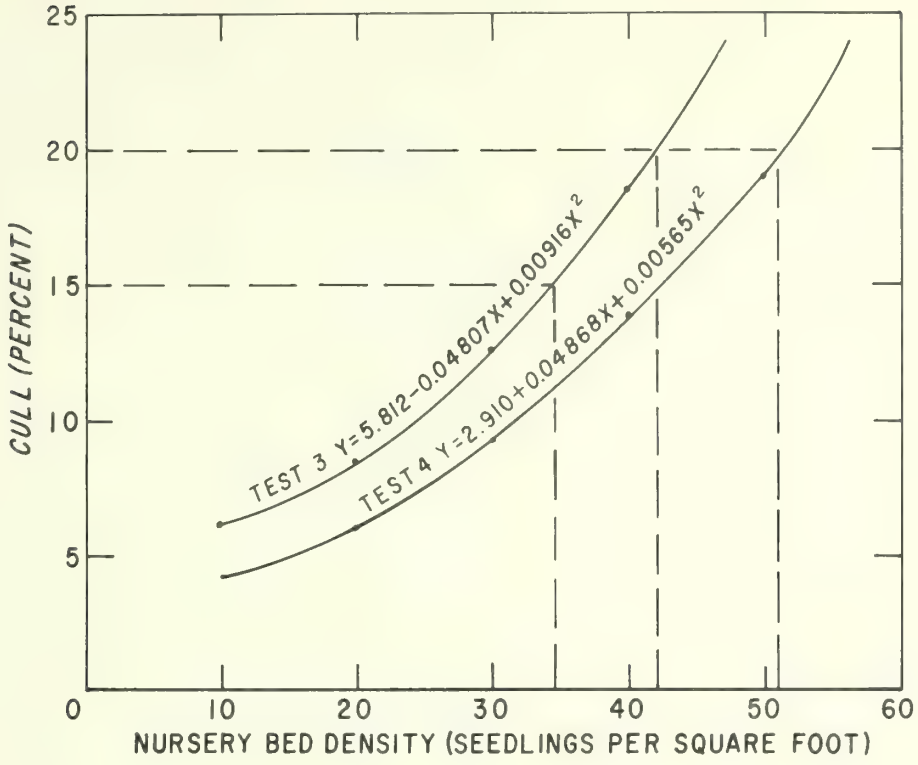

Figure 2.—Slash pine seedlings can be raised at comparatively high bed densities without excessive culling losses.

should be culled. His grading specifications for slash pine proved sufficiently accurate for predicting survival and growth without modification.

Seedling quality and foliar P content were inversely related — amounts were highest in Grade 3 seedlings and were progressively lower through Grade 1. Similarly, foliar P was highest in seedlings from the nursery whose product performed most poorly, suggesting a nutrient imbalance in these seedlings.

Each increase in bed density was accompanied by a decrease in the proportion of high-grade seedlings produced. Seedlings became smaller and the balance of tops to roots became poorer as the number of seedlings raised per square foot of nursery bed increased. Among plantable grades, the top-root ratio was best for Grade 1 seedlings grown at low bed densities.

Seedlings lifted and planted in late December and January survived and grew better than those lifted and planted earlier in December. Temperature and rainfall records suggest that differences were due to use of seedlings insufficiently hardened-off and to poor soil moisture conditions at the planting site. Normally temperatures are lower and the prospects for rainfall are better in January than in December.

The optimum nursery bed density for raising slash pines was estimated at 40 to 45 seedlings per square foot. Production curves were drawn from regression analyses, and optimum density was estimated by applying a maximum allowable cull factor (from all causes) of 20 percent. Estimates can be made by applying lower cull factors to the same set of curves.

Burns, Russell M., and Brendemuehl, R. H.
1971. Nursery Bed Density Affects Slash Pine Seedling Grade and Grade Indicates Field Performance. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SE-77, 7 pp.

Nursery bed density determined the number and influenced the grade of slash pine seedlings produced. Grade was a good indicator of 5-year field performance on refractory sandhill sites. Optimum nursery bed density for slash pine was estimated to be 40 to 45 seedlings per square foot, with a cull factor of 15 to 20 percent.

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Forest Service, U.S. Department of Agriculture
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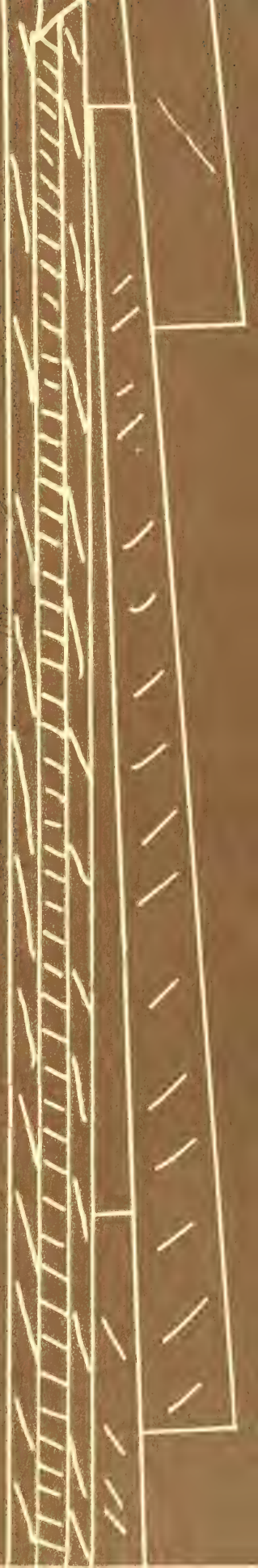
Asheville, North Carolina

The Effect of Air Conditioning on the Moisture Conditions in Wood Walls

J. E. Duff

USDA Forest Service Research Paper SE - 78 · January 1971



THE EFFECT OF AIR CONDITIONING ON THE MOISTURE CONDITIONS IN WOOD WALLS

by

J. E. Duff, Associate Wood Scientist
Forestry Sciences Laboratory
Athens, Georgia

INTRODUCTION

The maintenance of comfortable temperatures in dwellings by heating during winter and cooling during summer has found wide acceptance in this country. With the introduction of central heating and, often, of humidification, most homes have been insulated to increase heating efficiency. The use of efficient insulation in exterior exposed walls has resulted in steep temperature gradients through the wall during the cold season. In most instances, if a sufficient amount of moisture is allowed to penetrate an insulated wall, severe moisture accumulations can result.[1]

Research, as well as experience, has demonstrated the effectiveness of using vapor barriers on the interior side of the insulation to prevent these moisture accumulations in walls during the heating season.[2] As a result, adequately insulated walls with good interior vapor barriers have few moisture problems during the winter.

During the summer, cooling and the associated dehumidifying of the interior air below outside ambient conditions reverse the temperature and vapor pressure gradients from those found during the winter, although the gradients may not be as steep. In order to decrease the possibility of moisture accumulations during summer cooling, it would appear that the vapor barrier should be positioned on the warm exterior side of the insulation (rather than the interior side as practiced for winter heating). In many instances, however, dwellings are located in areas where both winter heating and summer cooling are used. In theory, the interior vapor barrier could increase chances for moisture to accumulate within the wall sections during the summer. However, it must be noted that the magnitude of these accumulations is unknown at present.

Condensation of moisture in air-cooled wood structures has been reported in a number of sites in the southern regions of the United States.[3] Presently, most of these incidents of severe condensation have been confined to poorly protected floors located over crawl spaces where moisture was abundant. Fewer instances of major con-

[1]Latta, J. K., and Beach, R. K. Vapour diffusion and condensation. Can. Building Dig. CBD-57, 4 pp. 1964.

[2]Teesdale, L. V. Condensation problems in modern buildings. USDA Forest Serv. Forest Prod. Lab. Rep. 1196, 18 pp. 1959.

[3]Verrall, A. F. Condensation on air-cooled buildings. Forest Prod. J. 12: 531-536. 1962.

densation have been reported in structural wall sections, with the exception of walls adjacent to shower facilities or other areas with high water vapor. No doubt, dewpoint temperatures inside insulated wall sections have often caused condensation or higher-than-normal moisture levels, but these have gone unobserved because of their transient nature. Normally, such conditions must exist for prolonged periods before the results of moisture condensation are evident from outside the wall. Dewpoint temperatures have occasionally been recorded in floors, but the wood joists did not reach an excessively high moisture content. However, even transient condensation may produce higher-than-normal moisture content which could result in excessive dimensional changes in the wood. For example, the unanticipated increase in moisture content from transient condensation has been reported to cause buckling of floors (see footnote 1).

Extensive condensation and accumulation of moisture within wall and floor sections create unusual moisture environments in which mold, mildew, and decay fungi can flourish. Unlike condensation problems in winter, the temperatures in wall and floor sections of air-conditioned structures are in a suitable range to promote fungal activity. Such growth could lead to discoloration of paint film and wood deterioration in extreme cases.

This study was undertaken to determine how air conditioning during the summer affects moisture accumulations in insulated wood walls with vapor barriers on the interior side of the insulation. Emphasis was placed on the magnitude of moisture gradients, their duration over several 24-hour periods, and the effects of the direction of exposure on moisture accumulations. No attempt was made to measure the actual moisture content of wood wall members, although moisture conditions on both sides of the exterior plywood sheathing were monitored.

MATERIALS AND METHODS

Environmental Exposure Structure

This study was conducted at the Southeastern Forest Experiment Station's Whitehall environmental structure in Athens, Georgia (fig. 1). The 24- by 24-foot structure contains removable 4- by 8-foot sections in each wall.

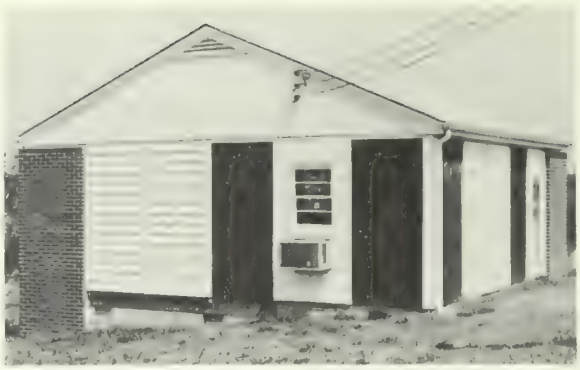


Figure 1.—Whitehall environmental exposure structure at Athens, Georgia.

Experimental Panels

For the present study, four 4- by 8-foot wall sections were constructed, each consisting of two 2- by 8-foot study panels. Each set of study panels faced a different cardinal direction. Each wall section consisted of three vertical 2- by 4-inch studs, approximately 24 inches on center, an outer sheathing of $\frac{3}{8}$-inch exterior-type softwood plywood, 3-inch fiberglass batt insulation (without vapor barrier) between studs, a 0.006-inch polyethylene vapor barrier on the inner stud faces, and $\frac{1}{2}$-inch gypsum board as the interior surface. The entire panel was nailed. Conventional bevel lap siding of redwood was installed over the exterior sheathing and painted white. The gypsum board surface was painted with two coats of interior latex white paint. The study panels were then installed in the test structure (fig. 1).

Moisture and Temperature Measurement

Wood moisture probes[4] were used to measure moisture content at selected points in the eight 2- by 8-foot study panels. The probe consists of a small strip of wood (0.07- by 0.07- by 0.75-inch) coated on two opposite faces with conductive silver paint; moisture content is indicated as a function of the electrical resistance of the wood between these silver electrodes.

Temperature was recorded with copper-constantan thermocouples adjacent to the probes. The moisture and temperature sensors were installed in the center of each

[4]Duff, J. E. A probe for accurate determination of moisture content of wood products in use. Forest Prod. Lab., U.S. Forest Serv. Res. Note FPL-0142, 10 pp. 1966.

study panel during the fabrication of the experimental wall sections (fig. 2). Wire leads to the sensors were extended to the top of each wall section for subsequent connection to the automatic system for data collection, where the measurements were recorded on paper tape (fig. 3). The punched paper tape was fed into the 1601 and 7094 IBM computers for processing.

Experimental Procedure

The interior of the Whitehall environmental structure was air-conditioned at 75° F. ± 2° F. No attempt was made to control the relative humidity of the interior. Moisture and temperature data were collected at 2-hour intervals for several days during the months of June and July 1967.

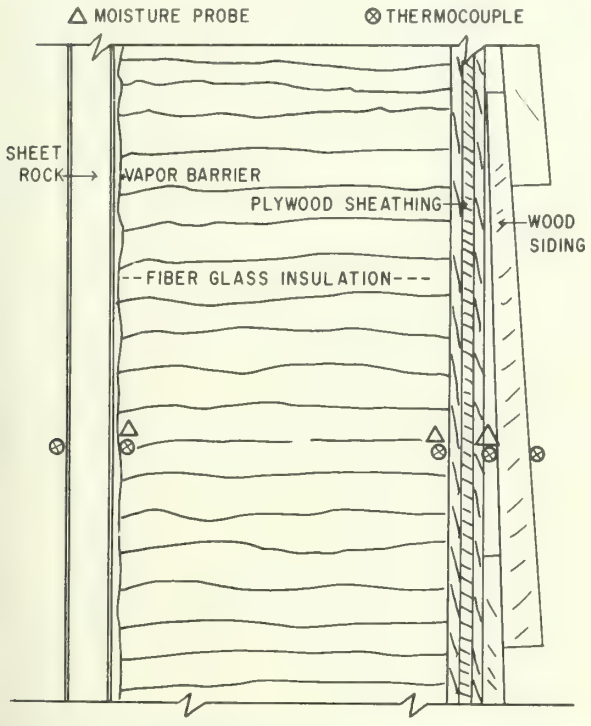


Figure 2.—Cross-section of a wood frame study panel. Note the position of the moisture and temperature sensors.

RESULTS AND DISCUSSION

Effect of a Clear Day

The moisture and temperature gradients across the insulated walls varied considerably during any given 24-hour period. Figure 4 shows a typical 24-hour time plot of the moisture content and temperature measure-

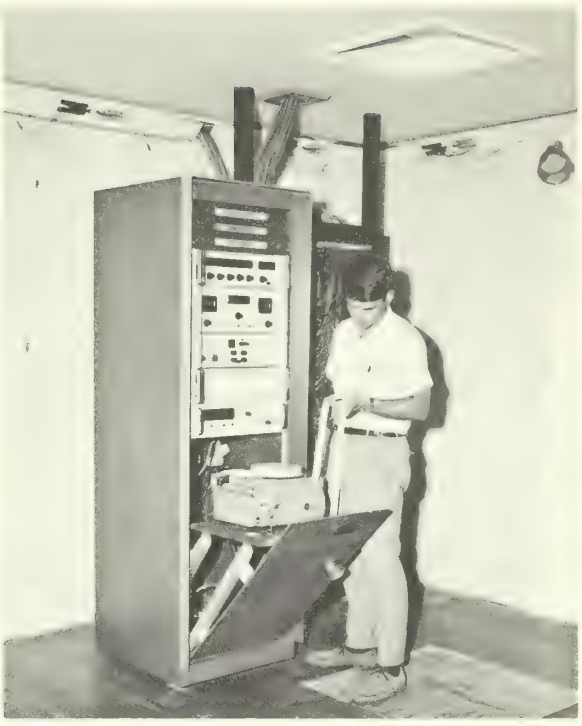


Figure 3.—The fully automatic system for data collection used in this study.

ments taken on the interior and exterior surfaces of the insulation. This plot of a wall facing south was taken on a clear day (maximum temperature of the outside air was 89°F.). The plot shows that the temperature on the exterior surface of the insulation decreased from midnight until sunrise. As the sun warmed the outside ambient air and the exterior surface of the wall, the temperature on the exterior surface of the insulation increased steadily to a peak of 92°F. at 4 p.m. and subsequently decreased as the temperature of the outside air dropped. The temperature of the interior surface of the insulation remained constant until about 8 a.m. It then began to increase slowly and peaked (77° F.) at the same time as the temperature of the exterior surface of the insulation. The gradient between the two surfaces clearly demonstrates the insulating properties of the fiberglass.

During this 24-hour period, moisture conditions, which were measured at the same locations as the insulation temperatures, showed some equally interesting trends. The moisture condition on the exterior side of the insulation dropped slightly during the period of increasing outside temperature (fig. 4). In contrast, the moisture conditions

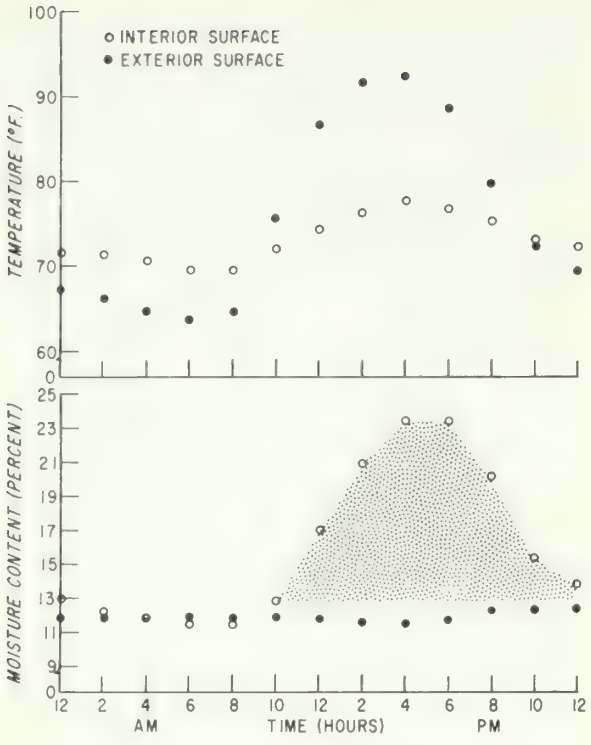


Figure 4.—Time plot of moisture and temperature conditions measured across the insulation of a wall section facing south on a clear day, June 18, 1967. The shaded area under the moisture content-time plot represents a measure of the amount of time in hours that the wall moisture content exceeded an arbitrary value of 13 percent.

on the interior side varied from a low of 12 percent at 6 a.m. to a peak of over 23 percent at 4 p.m. It is interesting to note that moisture and temperature peaked at the same time. This coincidence suggests that the temperature buildup on the exterior portion of the wall caused some of the moisture contained in the wood sheathing to be driven toward the cooler regions on the interior side of the wall.

The buildup in moisture content was due to the presence of the interior vapor barrier. Moisture migrating toward the cooler areas of the wall would normally pass into the cool interior of the structure. However, the vapor-resistant properties of the barrier prevented such transmission and caused a moisture buildup. The moisture buildup quickly decreased as soon as the temperature of the outside wall dropped.

The noticeable drop in moisture content of the interior surface from midnight until 6 a.m. indicated a loss of moisture to the cooler exterior regions of the wall. This loss did not show up as a gain in moisture on the exterior surface of the insulation; hence, the moisture must have moved into the center regions of the insulation.

Effects of a Cloudy Day

Figure 5 shows a 24-hour time plot of the same wall section on a cloudy day (maximum temperature of outside air was 82° F.). A comparison of figures 4 and 5 clearly shows the effects of a reduction in direct solar radiation on the exterior wall. The basic trends were essentially the same for both days except that peak moisture and temperature values were lower on the cloudy day.

The absence of visible solar radiation (some longwave radiation was probably present) reduced some of the energy available to heat the exterior areas of the wall. Hence, there was less of a driving force to move the moisture into the cooler regions of the wall. The peak moisture content shown in figure 5 was 7 percentage points lower in moisture content than that shown in figure 4. A more precise measure of the

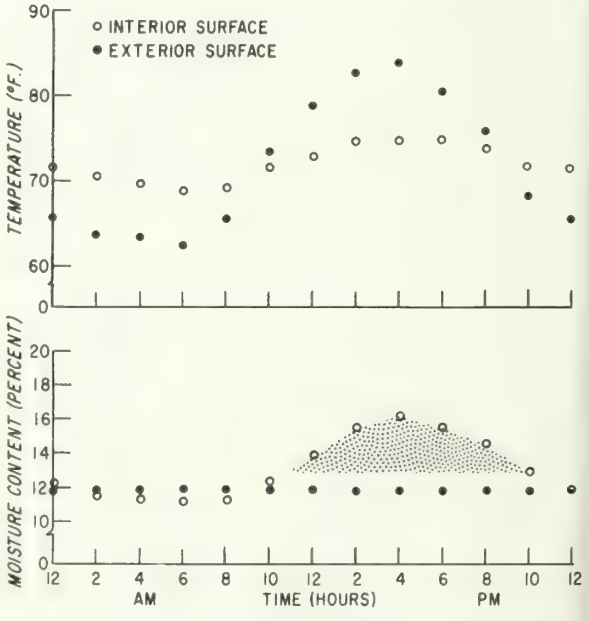


Figure 5.—Time plot of moisture and temperature conditions measured across the insulation of a wall section facing south on a cloudy day, June 15, 1967. The shaded area under the moisture content-time plot represents a measure of the amount of time in hours that the wall moisture content exceeded an arbitrary value of 13 percent.

effect of different amounts of solar radiation on the wall moisture content can be expressed as the length of time in hours that the moisture content exceeded an arbitrary level of 13 percent. The shaded areas under the curves in figures 4 and 5 are thus expressed in terms of "moisture content-hours." Thus, on the sunny day the effect of direct solar radiation represented a total of 81 moisture content-hours, while on the cloudy day this value was only 38, a reduction of approximately 50 percent.

Effect of Direction Exposure

A comparison of figures 4, 6, 7, and 8 demonstrates the effect of the direction of exposure on the moisture and temperature gradients in the insulated wood walls for one particular day. The highest temperatures on the exterior side of the insulation were recorded in walls facing east (97° F.) and west (99° F.), while a more moderate maximum was recorded in the south wall (92° F.). The lowest maximum was recorded in the north wall (88° F.). Temperature

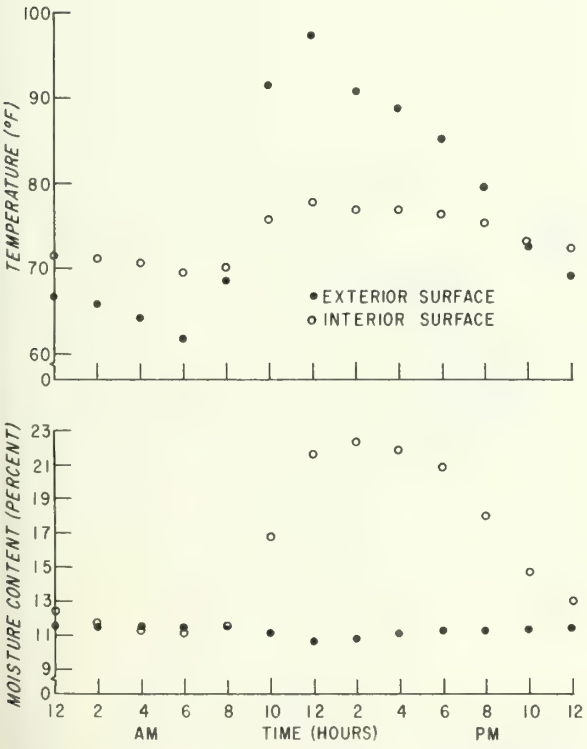


Figure 6.—Time plot of moisture and temperature conditions measured across the insulation of a wall section facing east on a clear day, June 18, 1967.

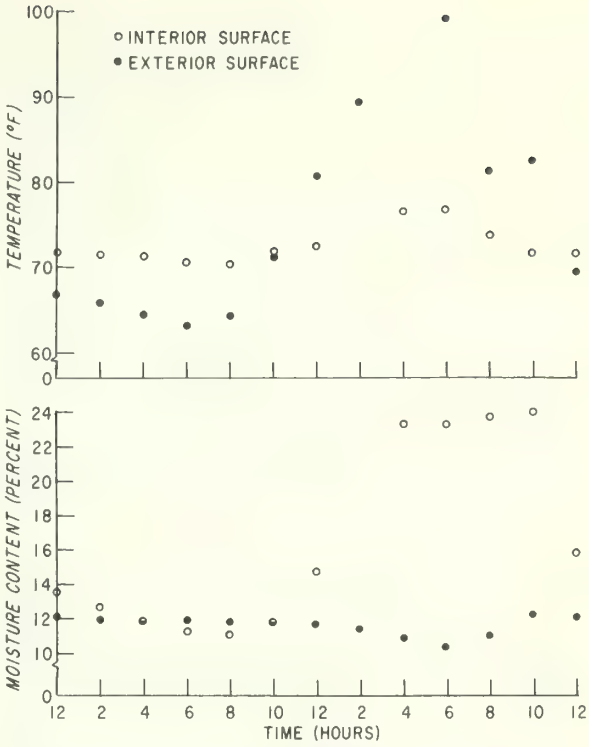


Figure 7.—Time plot of moisture and temperature conditions measured across the insulation of a wall section facing west on a clear day, June 18, 1967.

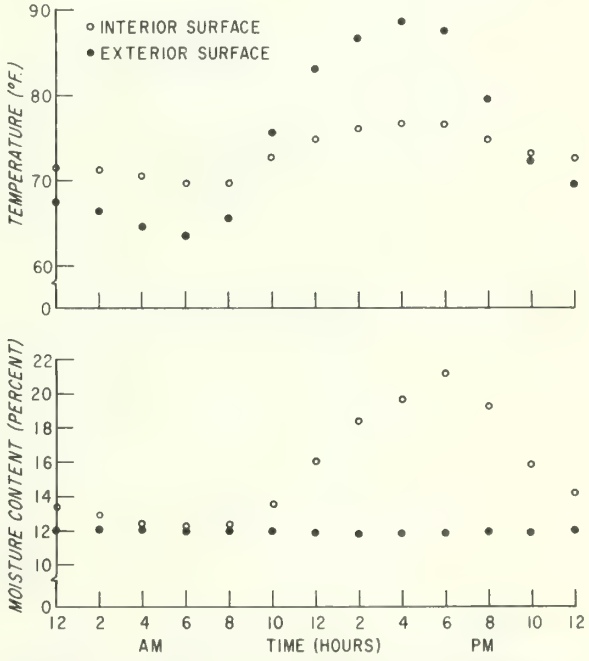


Figure 8.—Time plot of moisture and temperature conditions measured across the insulation of a wall section facing north on a clear day, June 18, 1967.

peaked earliest (12 noon) in the east wall because that wall received the effects of solar radiation before the other three. The remaining three walls peaked about the same time (within 2 hours), at about 4 p.m.

A comparison of the time plots for moisture content in figures 4, 6, 7, and 8 reveals that the peak values were similar (21 percent to almost 24 percent) for all walls. However, the duration of the period of high moisture content differed extensively among the walls. The south and west panels were rated the same (82 moisture content-hours), while the east wall had the highest duration (99 moisture content-hours). The north wall had the lowest value (56 moisture content-hours).

Trend of Daily Cycle

Figure 9 shows a moisture and temperature time plot of several consecutive 24-hour periods for a wall facing south. The periodic cycles of moisture content and temperature on both sides of the insulation are evident. As was pointed out earlier, the maximum values obtained for moisture content or temperature depend on what temperature the outside surface of the wall attains as a result of direct solar radiation or ambient air temperature.

A temperature or moisture gradient is positive when values increase toward the outside of the wall. Figure 9 clearly shows that the temperature gradient across the insulation is positive during most of the day and negative during a small portion of the night. This reversal of the temperature gradient causes the negative moisture gradient to drop to zero, or positive, during the night. It is evident that, in climates where the outside air temperature remains above the interior temperature, the moisture gradient probably would not drop to zero. In such climates the problems of excessive moisture accumulations as a result of air conditioning would be more likely. This trend can also be shown by comparing the moisture gradients for June 17 and 21 in figure 9. When the temperature of the exterior surface of the insulation dropped below that of the interior surface on June 17, the moisture gradient became positive. On June 21 the temperature gradient was also negative, but not to the extent that it was on June 17; hence, the moisture gradient remained negative on the 21st.

Moisture Gradient of Wood Sheathing

Figure 9 shows only a slight decrease in the moisture condition on the inside surface of the exterior sheathing (exterior surface of the insulation) during the period of peak solar radiation. Moisture conditions measured on the exterior surface of the sheathing (not plotted) were essentially identical with those on the interior surface of the sheathing for all four wall sections, indicating that the moisture content of the sheathing changed only slightly during any 24-hour day.

Mechanisms of Moisture Accumulation

The data presented suggest that there could be two basic mechanisms responsible for the accumulation of moisture vapor next to the interior vapor barrier. One mechanism, surface heating, which is clearly demonstrated in the data from all four wall sections, concerns the major influence of direct and indirect solar radiation on the exterior wall surfaces. When wood siding and sheathing of a given moisture content are heated on the surface, part of the contained moisture tends to leave the wood and seek a cooler region of the wall. In like manner, the moisture vapor contained in the air spaces within the wall most probably would be displaced to the cool interior when the wall surface is heated. Most of the excess moisture measured near the vapor barriers probably originated in the exterior regions of the walls. This conclusion is based on coincidence of maximum temperatures on the exterior wall and the maximum moisture contents within the wall.

The second mechanism, vapor pressure gradient, is often cited as being responsible for moisture condensation under air conditioning. This mechanism is based on the assumption that a vapor pressure gradient exists across the wall and that the gradient decreases toward the inside wall surface. This gradient is considered to be the driving force that causes the moisture vapor to migrate into the wall from the exterior environment and to build up eventually against the interior vapor barrier.

Certain temperature conditions must exist before this mechanism becomes an important source of moisture accumulation. First, there must be a positive temperature gradient maintained across the wall section (higher temperature outside than inside).

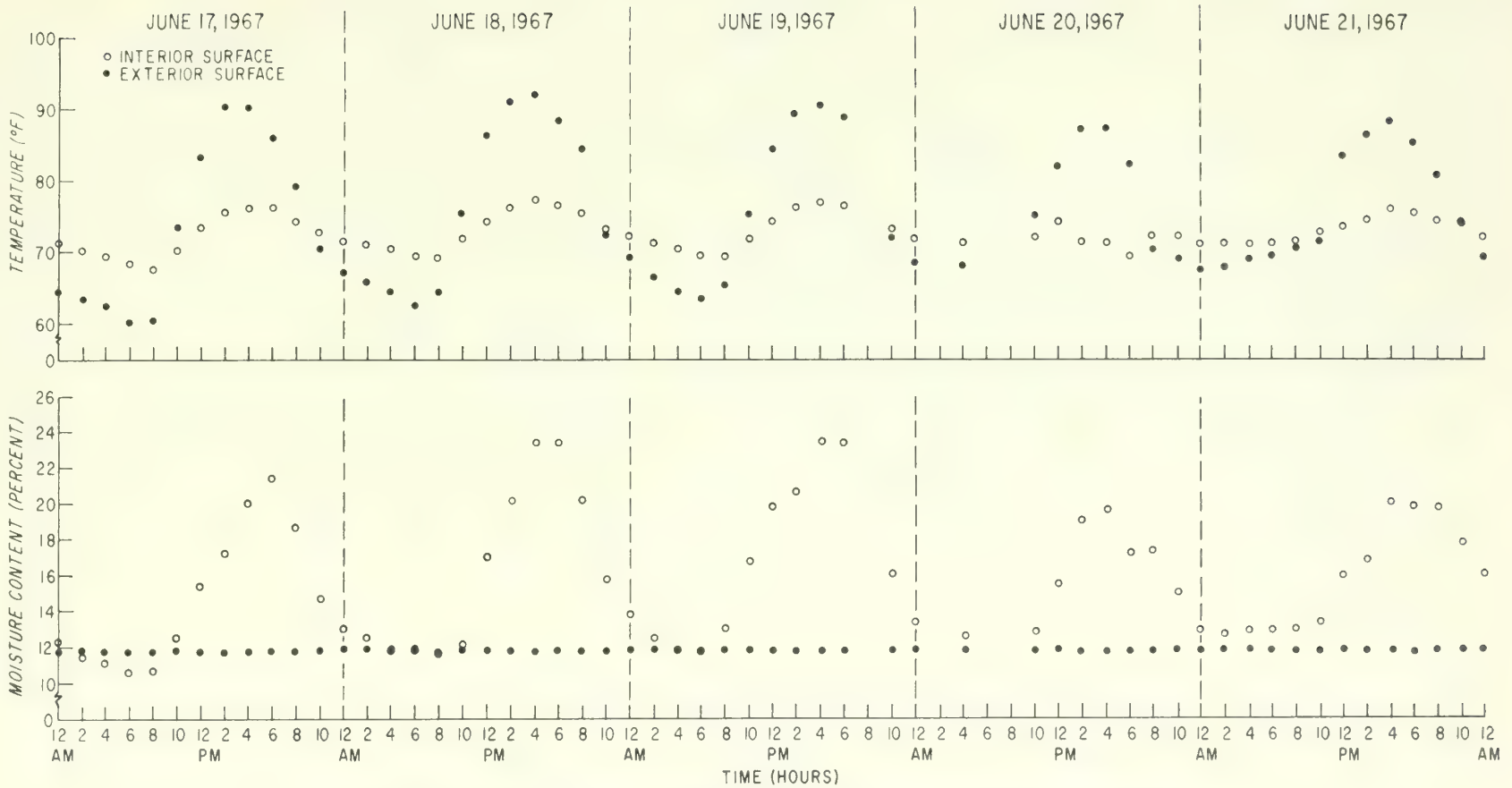


Figure 9.—Five-day sequence of moisture and temperature conditions measured across the insulation of a wall panel facing south.

Second, there must be moisture vapor available in the exterior environment such that a positive vapor pressure gradient can exist across the wall section. Third, the temperature and vapor pressure gradients must persist across the wall section for several 24-hour periods to allow sufficient time for a buildup of moisture. The resulting moisture-content gradients would remain negative at all times without rapid fluctuations.

A comparison of the temperature-time plots in this report clearly shows that a positive temperature gradient did not exist for more than a few hours each day. Similarly, the moisture gradients were negative for only a few hours each 24-hour period. Furthermore, the fact that the maximum moisture buildup never exceeded 24 percent indicates that no significant amount of moisture vapor was penetrating the wall from the exterior environment. Hence, the vapor pressure gradient probably did not contribute significantly to the moisture accumulations measured near the interior vapor barrier.

CONCLUSIONS

The severe moisture condensation that has been observed in exterior walls of air-conditioned buildings in other locations was not evident in the air-conditioned test house in north Georgia. The short daily intervals of high moisture contents recorded in the exterior insulated walls resulted from the heating of the exterior surface and subsequent movement of moisture toward the cooler interior portion of the wall cavity near the vapor barrier. The evidence indicates that there was no significant movement of moisture into the wall cavities from the exterior environment.

The absence of moisture condensation can be related to the reversal of the temperature gradient across the exterior wall cavities during the cool night hours. When the exterior temperature drops below the interior temperature, the flow of moisture vapor into a wall from the exterior is interrupted. For this flow to be significant, the exterior temperature must remain above the temperature of the air-conditioned interior for a substantial length of time.

Thus, the brief duration of the excessive moisture conditions in the exterior walls of the test house indicates that, in air-conditioned residences, no significant hazards exist that might cause wood decay or paint peeling in exterior insulated walls with an interior vapor barrier.

Duff, J. E.
1971. The Effect of Air Conditioning on the Moisture Conditions in Wood Walls. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SE-78, 8 pp.

In an air-conditioned test house in Athens, Georgia, moisture content and temperature gradients were measured across the insulation of exterior wood walls containing vapor barriers on the interior side of the insulation. A maximum moisture content of 24 percent was reached between the insulation and the interior vapor barrier. Each moisture peak clearly coincided with the maximum temperature peaks reached on the exterior wall surface during the daylight hours. The exterior temperature fell below the interior temperature during the night. These associations plus the relatively short duration of the moisture maximum (4 hours) indicated that, in air-conditioned residences, little if any moisture hazard exists in exterior insulated walls with interior vapor barriers.

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Southeastern Forest Experiment Station
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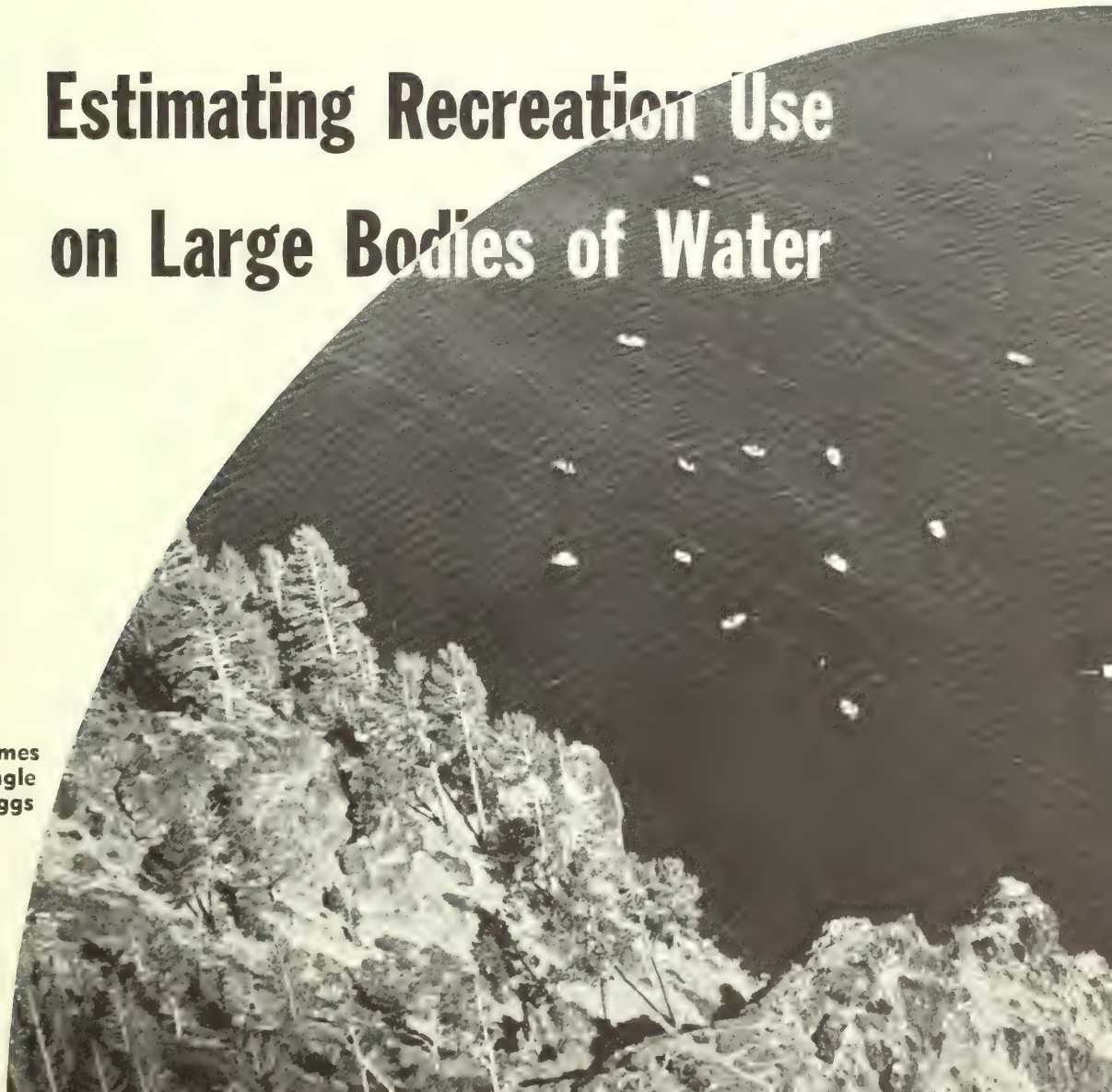
Estimating Recreation Use on Large Bodies of Water



by

George A. James
H. Peter Wingle
James D. Griggs

Estimating Recreation Use on Large Bodies of Water

by

George A. James, H. Peter Wingle, and James D. Griggs

Essential to the sound management of inland water for recreation is knowing the amount and kind of use the waters are receiving. An estimate of the number of boats and boaters will aid the manager in providing adequate boat launching facilities, trailer and vehicle parking spaces, and such public service facilities as restaurants, service stations, and comfort stations. Policy and regulations must be based on a knowledge of the kinds and amounts of water-oriented activities that occur; this will avoid conflicts of use and provide maximum safety and comfort to all users.

Current sampling techniques for estimating recreation on land have little direct application for estimating water-based recreation use. Some of the unique problems associated with sampling water-based use include the extreme dispersal of use, the great mobility of water users, the almost unlimited points of ingress and egress to many areas of water, and the innumerable bays and inlets which often hide boats and boaters from shore-based observation points.

James is Principal Recreation Specialist, Southeastern Forest Experiment Station, USDA Forest Service, Asheville, N. C. At the time of this study, Wingle was Recreation Staff Officer, Deschutes National Forest, Bend, Oregon. Griggs is Fishery Biologist, Oregon State Game Commission, Bend.

The objective of this study was to test a pilot sampling model for estimating recreation use that occurs on large bodies of water. Highly precise estimates of use were not required, and sampling intensity was made light intentionally to keep sampling costs reasonably low. A simpler sampling technique could have been used to estimate use on the lakes studied, but the comprehensive test was made to determine suitable procedures for sampling more complex situations. Procedures were designed to yield estimates of current use and to determine relationships between use and an easily obtained indicator of use that might be used to update estimates in future years.

The sampling model was tested during summer 1968 on East Lake and Paulina Lake in eastern Oregon. The lakes are located approximately 24 miles southeast of Bend, Oregon, on the Fort Rock Ranger District, Deschutes National Forest (fig. 1). Paulina Lake is 1,300 acres; East Lake is 1,000 acres. They are 1 mile apart at an elevation of approximately 6,330 feet above sea level. The shore around the lakes has received moderate development, and each has one lodge or resort, two or more developed campgrounds, and several boating sites with launching ramps. The primary recreation use is fishing and both lakes receive

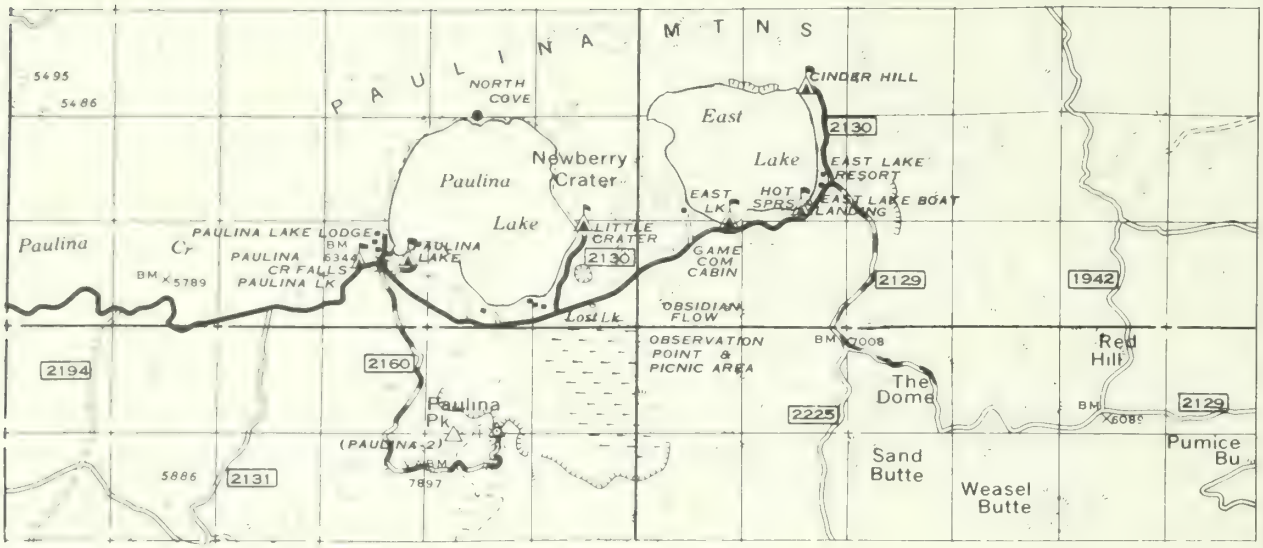


Figure 1.—East Lake and Paulina Lake, Fort Rock Ranger District, Deschutes National Forest in eastern Oregon.

heavy pressure, especially during early season. They are not popular for swimming or sailing, and the enforced 10-mile-per-hour speed limit precludes water skiing.

The study was originally planned as a Forest Service effort, using an observer in light aircraft to collect data by observational and photographic techniques. Ground checks were also planned to verify the accuracy of aerial observations and to obtain supplemental data not obtainable from the air. Before the study was started, however, it was learned that the Oregon State Game Commission planned to collect creel censuses and use data during 1968 on the two lakes. The agencies were interested in conducting a joint study, so only slight modification of the sampling procedures of both agencies was necessary to insure a more complete and comprehensive study than originally planned.

TECHNIQUES AND PROCEDURES

The sampling study covered the period May 25 (opening day of fishing season on high-elevation lakes) through September 2 (Labor Day). The recreation season of 101 days was sampled on 10 randomly selected days, equally divided between weekdays and weekend/holiday days.[1] The sample days included May 25; June 18 and 23; July 11, 13, 14, and 26; August 11, 19, and 27. Forest Service data were collected by an observer using aerial visual counts and photographic techniques; Game Commission data were collected by shore-based observers. Forest Service and Game Commission procedures are discussed separately below.

Forest Service Procedures

Five systematic flights, in light, single-engine aircraft, were made over each lake on each of the 10 sample days at approximately 0700, 0945, 1230, 1515, and 1800 hours; a time interval of 2¾ hours between flights. On each flight, the aerial observer made an instantaneous count of all boats on the water. On several flights, photographs were taken with hand-held camera to determine number of persons in each boat. The procedure was first to count the number of boats from an altitude of about 1,000 feet, and then make a second pass at 500 feet to take photographs of boats at an oblique

[1] The Game Commission study covered the period May 25 to September 30, inclusive, using 40 randomly selected sample days. This report used 10 sample days randomly selected from the Commission sampling frame and covers only the high-use season between May 25 and September 2.

angle of approximately 45° with the water. Airspeed was reduced to about 100 miles per hour, and pictures were taken out the open window.

Vehicle counts were obtained with pneumatic-tube, direct-reading counters placed at the entrances to Paulina Lake and East Lake campgrounds developed by the Forest Service. The principal boat launching area for each lake was located at the campground. Twenty-four hour traffic counts for each of the 10 sample days and a total season-long count were obtained at each campground.

Oregon State Game Commission Procedures

On each sample day, fishery biologists interviewed boaters as they returned to boat landing areas located at East Lake and Paulina Lake campgrounds. Hours of sampling were from 0700 to 1800 hours. Information collected included number of persons per boat by type of boat, hours boating time per person and per party, and creel census. The size and circular shape of the lakes made it possible to count boats on them from a boat landing area in a campground on each lake. On each of the 10 sample days on which Forest Service flights were made, Commission personnel used binoculars to count boats on each lake at 0700, 1000, 1200, 1500, and 1800 hours. Counts were made within 10 minutes of each other at the two lakes.

ANALYTICAL PROCEDURES

Estimates of total boating use, number of boats, and number of boaters were based on three statistics: (1) number of boats per hour, (2) average number of persons per boat, and (3) average hours of boating per person. A description of how each variable was measured is presented below:

Number of Boats per Hour

Calculations for estimating number of boats per hour, on each sample day, were based on the assumption that instantaneous count of boats made during each flight[2] represented the number of boats on the water *each hour* during the observation period. The average time interval between flights was 2¾ hours. Thus, if 50 boats were observed on the water during an observation period, it was assumed that an average of 50 boats were present each hour during the entire period of 2¾ hours. It is unlikely that the same boats remained the entire period. Many boats were observed on shore during each period, and there was almost constant movement of boats to and from shore and to and from each lake. And, although sudden storms or squalls could result in considerable change in number of boats within a short period of time, it is believed that the number of boats per hour did not vary greatly within each observation period. More frequent aerial flights to reduce the time interval would likely increase accuracy, but sampling costs also would be proportionately higher.

Number of Persons per Boat

Oregon State Game Commission personnel made a count of persons per boat as boats returned to the landing checkpoints. Forest Service persons-per-boat data were obtained from aerial photographs.[3] Microscopes and magnifying glasses were used to count number of persons per boat from aerial photographs. Counts from the ground of persons per boat, all boat types, were slightly larger on both lakes than counts made from aerial photographs (table 1). The means determined by the two methods were not significantly different for East Lake, but were significantly different at the 95-percent level of probability for Paulina Lake. A careful count made on the ground at boat landing areas is more precise than aerial photography for determining number of persons per boat. Mean number of persons per

[2] Two of the 50 planned flights were canceled because of adverse weather. Counts of boats made by shore-based observers on these two occasions were used in the analysis.

[3] Prestudy aerial flights revealed that persons in boats could not be counted accurately at the 500-foot minimum altitude set by Forest Service and FAA regulations. Many persons could not be seen with the unaided eye and binoculars were impractical.

Table 1.—Number of persons per boat, all boat types, by two counting techniques

Technique	East Lake			Paulina Lake		
	Mean	Confidence interval[1]	Observations	Mean	Confidence interval[1]	Observations
	Number	*Percent*	*Number*	*Number*	*Percent*	*Number*
Ground observation	2.53	± 7.1	233	2.61	± 11.2	106
Aerial photographs	2.40	± 18.2	315	2.27	± 9.4	142

[1] Confidence interval at the 95-percent level of probability, expressed as percentage of the estimate.

boat determined by count from the ground—2.53 for East Lake and 2.61 for Paulina Lake—were used in the analysis. Commission data were collected separately for open powerboats, covered powerboats, and other types, such as rowboats and canoes. The means were not significantly different by type of boat or by lake.

The major disadvantage of aerial count is inability of the observer to determine number of persons in covered boats. The slight differences between ground and aerial counts in this pilot study, however, had little statistical significance and demonstrate that either technique could have been used to determine number of persons per boat.

Hours of Boating per Person

Hours boating time per person per trip[4] was the last statistic required for calculating use estimates. This information was collected by Commission personnel from persons returning to the boat landing checkpoints. On East Lake, mean time per boating trip was 3.38 hours; on Paulina Lake, it was 3.05 hours. Confidence intervals at the 95-percent level of probability, expressed as percentage of the mean, were ±18.5 percent for East Lake and ±18.3 percent for Paulina Lake.

[4] Information was not obtained from interviewees concerning number of trips made each day nor total hours of boating for the entire day.

RESULTS

Simple linear regression analysis was used to produce estimates of total boating use, number of boats, and number of boaters for each lake. The form was: $\hat{Y} = a(N) + b(X_s)$, where "a" and "b" are constants, "N" is number of days in the recreation season, and "X_s" is season-long traffic count. The independent variables used for regression were separate traffic counts made at the entrances to East Lake and Paulina Lake campgrounds.

Total Boating Use

The first step was to calculate total hours of boating on each lake for each sample day. Total hours of boating was the sum of the number of boats per hour multiplied by average number of persons per boat. Regression analysis was run to produce a season-long estimate of total boating use. The more precise estimate for each lake was obtained using the traffic-count record from Paulina Lake Campground. Estimates, regression formulas, and confidence intervals are shown below:

$\hat{Y}$ (Total boating use, East Lake) = —302.1 (101) + 2.4796(80,289) = 168,574 hours or 14,048 visitor-days.[5]

[5] A visitor-day is recreation use which aggregates 12 person-hours. It may entail one person for 12 hours, 12 persons for 1 hour, or any equivalent combination of individuals or group use, either continuous or intermittent.

Confidence interval at the 67-percent level of probability, expressed as percentage of the estimates, was ±9.3 percent; coefficient of determination (r^2) was 0.834.

$$\hat{Y} \text{ (Total boating use, Paulina Lake)} = -408.9(101) + 1.7874(80{,}289) = 102{,}213 \text{ hours or } 8{,}518 \text{ visitor-days.}$$

Confidence interval at the 67-percent level of probability was ± 19.0 percent, coefficient of determination (r^2) was 0.727.

As a check on the boating use estimates produced by regression, estimates were also generated using simple random sampling methods. Total boating use estimates using this method were 13,274 visitor-days for East Lake and 7,960 visitor-days for Paulina Lake.

Number of Boats

Number of boats on each lake on each sample day was calculated with the following formula:

$$\text{Number of boats} = \frac{\text{Hours boating use}}{\text{Avg. hrs. use per boat}}$$

Regression analysis was run to produce a season-long estimate of total number of boats using each lake. A more precise estimate for each lake was obtained from the traffic-count record at Paulina Lake Campground. Estimates, regression formulas, and confidence intervals are shown below:

$$\hat{Y} \text{ (Number of boats, East Lake)} = 20.7(101) + 0.2097(80{,}289) = 18{,}928.$$

Confidence interval at the 67-percent level of probability was ± 10.8 percent, coefficient of determination (r^2) was 0.775.

$$\hat{Y} \text{ (Number of boats, Paulina Lake)} = -37.7(101) + 0.1949(80{,}289) = 11{,}840.$$

Confidence interval at the 67-percent level of probability was ± 20.2 percent, coefficient of determination (r^2) was 0.720.

Number of Boaters[7]

Number of boaters on each lake on each sample day was calculated with the following formula:

$$\text{Number of boaters} = \text{Mean number of persons per boat} \times \text{number of boats.}$$

Regression analysis was run to produce a season-long estimate of total number of boaters using each lake. Again, a more precise estimate for each lake was obtained from the traffic-count record at Paulina Lake Campground. Estimates, regression formulas, and confidence intervals are shown below:

$$\hat{Y} \text{ (Number of boaters, East Lake)} = -11.0(101) + 0.6165(80{,}289) = 48{,}387.$$

Confidence interval at the 67-percent level of probability was ± 9.1 percent, coefficient of determination (r^2) was 0.865.

$$\hat{Y} \text{ (Number of boaters, Paulina Lake)} = -81.2(101) + 0.4950(80{,}289) = 31{,}542.$$

Confidence interval at the 67-percent level of probability was ± 20.0 percent, coefficient of determination (r^2) was 0.703.

All use that occurred on the lakes before and after the period in the sample season must be added to the above estimates to produce year-long estimates for 1968.

[6] Example: if estimated season-long boating use is 10,000 visitor-days *for a given sample,* and the confidence interval is ± 10 percent at the 67-percent level of probability, we construct the interval 9,000 to 11,000 visitor-days. On the average, 67 percent of such intervals will include the true value if we sample an unlimited number of times.

[7] Kind of activity pursued was not determined in this study, although almost all boat use on the lakes was for fishing.

Boating use on both lakes was well distributed over the entire day, as shown in the following statistics based on instantaneous aerial counts made on sample days.

Time	East Lake (Percent)	Paulina Lake (Percent)
0700	14.4	13.0
0945	24.4	30.3
1230	21.0	20.4
1515	23.8	20.3
1800	16.4	16.0

DISCUSSION

The primary objective of the pilot study was successfully met. The study provided a good test of sampling techniques and resulted in a useful tool for obtaining estimates of recreation use. Provision for the updating of use estimates for a several-year period, based on regression formulas developed during the calibration year, greatly reduces sampling cost. And, although some estimates contained a rather large amount of error, they are still useful for making management decisions. Each manager must determine precisely the time and money requirements for his particular sampling problem, and plan accordingly.

Ground observation is less costly than aerial observation and should be used whenever possible. The only requirement is that the lakes be of such size and shape that observers can count all boats on the water from one or more points on shore. In this pilot study, estimates of use could have been obtained for both lakes using ground-observation techniques alone. Had this been done, the two lakes could have been sampled at an approximate cost of $2,150, as shown below:

Personnel (interviewing and counting boats) 20 sample days, approximately 13 hours each day, at $5 per hour	$1,300
Personnel (supervision) 40 hours at $7.50 per hour	300
Transportation (includes servicing of traffic counters) 1,000 miles at 10¢ per mile	100
Equipment (binoculars and traffic counters)	150
Analysis and report preparation	300
Total cost	$2,150

Cost prorated over a 5-year period, for which use estimates can likely be updated, will average approximately $430 annually.

Where a higher degree of precision is required over that obtained in this pilot study, greater sampling intensity will be necessary. There is little further cost reduction possible in sampling situations where ground-observation techniques alone can be used. But calibration costs are reasonable, and doubling sampling intensity to 20 days on each lake would increase total cost only approximately $1,500 for travel and interviewing.

Most sampling situations will likely involve lakes of large size and irregular shape where an instantaneous count of boats cannot be made effectively by shore-based observers. In these situations, a combination of aerial and ground observation must be used. Total cost of sampling both lakes, using aerial and ground observation techniques, is shown below:

Aerial flights 50 flights at approximately $30 per hour	$1,500
Personnel (aerial observation and photo interpretation). 100 hours at $7 per hour	700
Personnel (interviewing) 20 sample days, approximately 13 hours each day, at $5 per hour	1,300
Personnel (supervision) 40 hours at $7.50 per hour	300
Ground transportation (includes servicing of traffic counters) 1,000 miles at 10¢ per mile	100
Film (both black and white and color)	50
Equipment (traffic counters, magnifying glass; does not include cost of photographic equipment)	150
Analysis and report preparation	300
Total cost	$4,400

Cost prorated over a 5-year period, for which use estimates can likely be updated, will average approximately $880 annually.

There are several ways that sampling costs might be reduced when both ground and aerial observation are necessary. Essential information concerning number of persons per boat and hours of boating per person can best be obtained by shore-based interviewers. Aerial photography will likely be needed only in situations where use is too congested to permit an accurate boat count by aerial observers. Where photography is not needed, sampling costs will be less because of reduced flying time over each area of water and elimination of the need for photographic equipment, film, and photo interpretation. The principal cost in aerial sampling is flight time between landing strip and area of water; once over the water, little time generally is required to count boats. In many instances, two or more areas of water might be sampled for little more than the cost of one. For example, a test flight was made over six lakes (including East and Paulina lakes) during the pilot study. Total flying time to cover all six lakes was 1¾ hours, compared with 1 hour's flying time for East and Paulina lakes only. All six lakes could have been sampled at an additional flying time cost of approximately $1,100. Other sampling costs would also increase, but at a rate considerably less than for a single area of water.

The ground-sampling aspect of the technique lends itself very nicely to cooperative efforts between recreation planners and fisheries managers. Where creel census information is needed and planned, sampling costs might be effectively shared between two or more agencies.

Aerial sampling is expensive; the cost may be prohibitive where greater sampling intensity is necessary to obtain highly precise estimates of use. When additional flights are required to increase sampling intensity, the authors recommend the technique only where several areas of water can be covered during each flight.

Other sampling techniques must be tested to determine which will produce the best estimates at lowest cost. These include:

(1) Stratified random sampling, using ground interviewers, where *all* boat launching sites are sampled. This technique would eliminate the need for aerial flights.

(2) Self-registration, where all boaters are requested to complete a short questionnaire as they leave the water at boat landing sites.

(3) High-altitude aerial photography, coupled with ground observation, where only a few pictures need be taken to photograph boats on several areas of water.

Continuing research to design and test sampling procedures will provide recreation managers and planners with the necesary tools for managing the recreation resource more effectively and inexpensively.

James, George A., Wingle, H. Peter, and Griggs, James D.
1971. Estimating Recreation Use on Large Bodies of Water. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SE-79, 7 pp.

The paper describes a pilot sampling technique for estimating recreation use that occurs on large bodies of water and includes recommendations for future sampling. Procedures were tested on East Lake and Paulina Lake in Oregon in 1968.

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Forest Service, U.S. Department of Agriculture
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Asheville, North Carolina

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Polymorphic Site Index Curves for White Pine in the Southern Appalachians

by

Donald E. Beck

U. S. Department of Agriculture—Forest Service
Southeastern Forest Experiment Station
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POLYMORPHIC SITE INDEX CURVES FOR WHITE PINE IN THE SOUTHERN APPALACHIANS

by

Donald E. Beck, Principal Silviculturist

Site index — the height of the dominant stand at some particular age — is the commonly used yardstick by which relative productivity of forest sites is measured. In stands younger or older than index age, a family of height/age curves is required for projecting measured height to the height at index age. Most such curves now in use were constructed using the methods described by Bruce (1926). These methods involve measuring height and age of many stands at a single point in time, fitting an average curve of height on age to these data, and constructing a series of higher and lower curves with the same shape as the guide curve.

Evidence has accumulated in recent years that the curves constructed in this manner often do not represent accurately the growth of stands. In the first place, the guide curve is accurate only if the ranges of site indices are equally represented at all ages. Spurr (1955), King (1966), and Curtis (1964) report that unequal sampling frequently occurs because of the patterns of cutting and land abandonment in a particular region. For example, trees reach merchantable size faster and are often cut at younger ages on the higher quality sites. Consequently, a sample of stands drawn at one point in time would likely result in a lower average site index in older stands than in the young stands. A guide curve constructed from such a sample could not accurately depict actual growth trends. The second source of error is the assumption that the shape of the curve does not vary from site to site, i.e., the site curves are anamorphic. This assumption has been proved false for several species (Bull 1931; Spurr 1952, 1955; King 1966; Stage 1963; Brickell 1966, 1968).

The site index curves currently being used to evaluate site quality in natural stands of eastern white pine (*Pinus strobus* L.) in the Southern Appalachians were constructed by the anamorphic technique (Doolittle and Vimmerstedt 1960). These curves are subject to both sources of error mentioned above. A recent investigation[1] showed that the published Doolittle-Vimmerstedt curves result in biased estimates of site index, particularly in young stands. Figure 1 compares actual growth to pattern of growth predicted by the published site index curves for representative stands of low, medium, and high site index. In all three circumstances, measured rate of growth below index age 50 was much slower than predicted by the site index curves. Beyond index age, measured rate of growth was slightly greater than predicted growth rate.

[1] Beck, Donald E. Height growth patterns in eastern white pine in the Southern Appalachians. 1969 (Unpubl. Ph.D. diss., N. C. State Univ., Raleigh.)

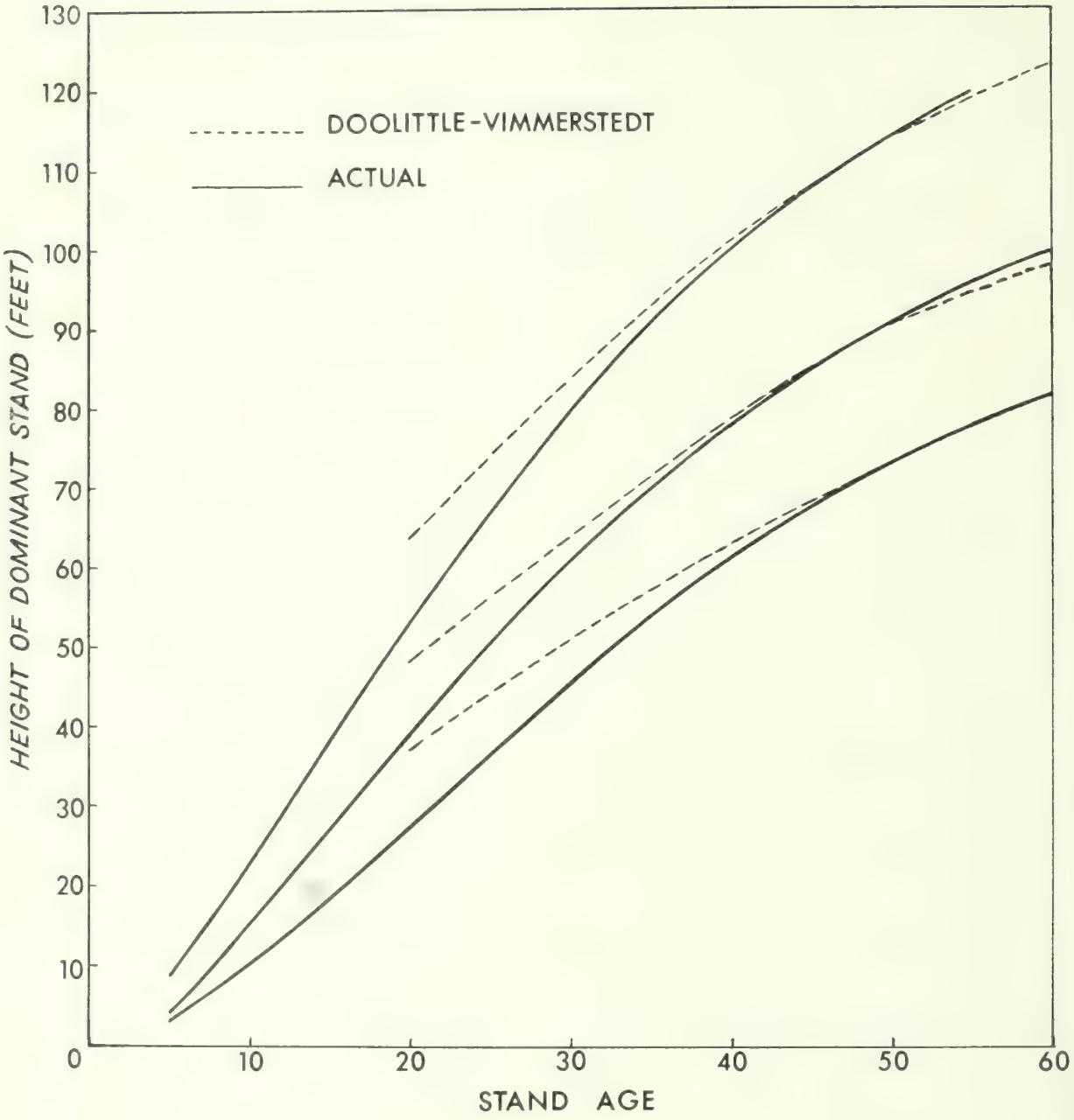

Figure 1.—Actual height-growth curves for three representative stands compared to the Doolittle-Vimmerstedt site curve predictions for similar sites.

If the published site index curves had been used to predict site index when these stands were 20 years old, actual site index would have been underestimated by 14 to 20 feet. As a result, board-foot yields at a rotation age of 70 would be underestimated by as much as 22 M bd. ft. per acre, or nearly 40 percent of actual yields. Consistent underestimation of this magnitude could cause serious underevaluation of forest land and mismanagement of forest stands.

Discrepancies shown in figure 1 suggest a sampling bias in the published curves in which a disproportionate number of high quality sites were represented in the young age classes. Though not as readily evident, failure to allow for polymorphic growth trends also may be contributing to the discrepancies between measured and predicted growth trends.

This paper presents new site index curves for natural, even-aged stands of white pine in the Southern Appalachians. These new curves are based on measured growth of stands and make allowances for polymorphic growth trends.

DATA COLLECTION

The study data were obtained from 42 even-aged stands of white pine of natural origin. At least 75 percent of the dominant and codominant trees in each stand were white pine. These stands were located in the mountains of southwestern Virginia, eastern Tennessee, western North Carolina, and northern Georgia—the southernmost range of eastern white pine—over an elevational range from 1,350 to 3,050 feet. Topography included slopes from 0 to 57 percent, many degrees of exposure, and positions ranging from stream bottoms to ridgetops. Site index (index age 50) ranged from 71 to 122. Stand age ranged from 44 to 70 so that measured height at index age was available for all but a few stands.

Three trees in each stand were selected from the dominant and codominant crown classes for measurement of the height/age relationship. These trees were free from injury and disease and had not been suppressed as evidenced by the annual rings. After felling, height at successive ages was determined by internode measurement. Nodes on the lower bole of the larger trees were frequently obscured by natural pruning and subsequent diameter growth. When the nodes were obscured, the lower 15 to 20 feet of the bole was split along the pith to avoid errors in determining heights. Ring counts were used also as a check on height determined by internode measurement.

For each sample tree the diameter of and distance to competing trees were measured for conversion to a measure of surrounding density. On each plot mean elevation above sea level, aspect in degrees, steepness of slope in percent, and position (stream bottom, lower, middle, or upper slope) were recorded.

SITE INDEX CURVES

The site index curves were developed in three steps:

1. Selecting a mathematical model that satisfactorily described the growth of individual stands.

2. Determining if and how the pattern of growth varied among stands of different site index and providing for change in shape of the curve in the mathematical model.

3. Testing to see if stand density and some topographic features of the site affected shape of the curve.

Each step is described more fully in the Appendix.

The resulting equation which expresses height as a function of age and site index is:

$$H = [63.06 + 0.67(S)]\left\{1 - e^{-[0.00985 + 0.00033(S)]t}\right\}^2 \quad (5)$$

where H is total height at age t, S is site index at index age 50, and e is base of the natural logarithms. This equation allows the pattern

of height growth to vary with the level of site index. Figure 2 shows the family of curves generated by solution of the equation for selected values of site index.

APPLICATION OF THE CURVES

These site index curves apply to naturally established, even-aged stands of white pine in the Southern Appalachians. To estimate average site index in such stands, measure total height and total age of at least three dominant and codominant trees per plot or location of uniform site conditions. The trees selected should appear to have been in the dominant stand throughout their lives and show no evidence of damage, disease, or any condition which may have adversely affected height growth. The curves should be entered with the average height and age of the selected trees on each plot.

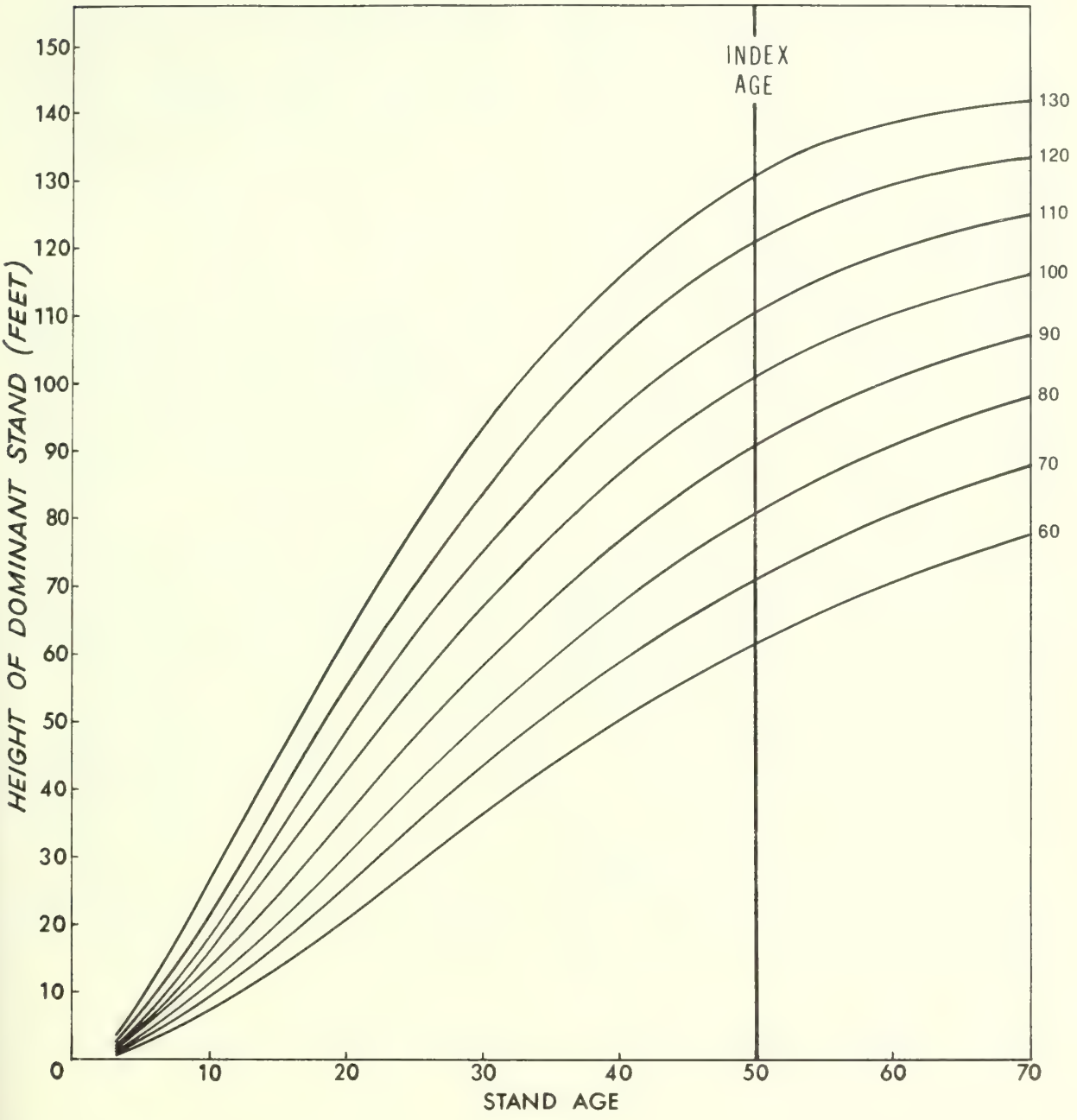

Figure 2.—Polymorphic site index curves for natural stands of eastern white pine in the Southern Appalachians.

APPENDIX

The Model

Graphs of height on age for individual trees and stands showed the characteristic sigmoid, or S-shaped, trend described by Spurr (1952). Investigation of a large number of sigmoid functions, including those discussed by Grosenbaugh (1965), led to Richards' (1959) modification of the Bertalanffy equation (Bertalanffy 1938, 1957). This model was suggested for use in describing growth of trees by Cooper (1961) and applied to height growth of Engelmann spruce and inland Douglas-fir by Brickell (1966, 1968).

The form of equation used in this study was:

$$H = A\left(1 - e^{-kt}\right)^{\frac{1}{1-m}} \qquad (1)$$

where H is height at age t, e is the base of natural logarithms, and A, k, and m are parameters to be estimated. This model has the properties, for certain values of the parameters, required to generate an asymmetrical S-shaped curve that passes through the origin and approaches a maximum height as age approaches infinity.

Deriving the Site Index Curves

Coefficients of the growth model (equation 1) were estimated for each of the 42 stands with an iterative least-squares fitting procedure. Then, to determine if the shape of the growth curve varied from one level of site index to another, the estimates of the coefficients A, k, and m (which determine curve shape) were examined in relation to site index by graphing and by regression analysis. It was found that both A and k were highly significantly related to site index by linear equations of the form:

$$A = b_0 + b_1(S) \qquad (2)$$

$$k = c_0 + c_1(S) \qquad (3)$$

where S is site index and b_0, b_1, and c_0, and c_1 are coefficients to be estimated. The coefficient m was apparently randomly distributed with respect to site index and average value of m was shown by t-test to be not significantly different from 0.5. Because it greatly simplified the growth equation, the coefficient m was allowed to take a value of 0.5.

Thus, allowance for varying shape of curve from site to site was made by expressing the coefficients A and k as functions of site index in the growth model (equation 1). The coefficient m was held constant at 0.5 making the quantity $\frac{1}{1 - m}$ equal to 2. The function:

$$H = [b_0 + b_1(S)]\left\{1 - e^{-[c_0 + c_1(S)]t}\right\}^2 \qquad (4)$$

was fitted to the combined data for all stands by the iterative least squares procedure. The equation:

$$H = [63.06 + 0.67(S)]\left\{1 - e^{-[0.00985 + 0.00033(S)]t}\right\}^2 \qquad (5)$$

was used to calculate the polymorphic site index curves (index age 50) shown in figure 2.

Testing for Effect of Stand and Site Factors

To explain additional variation in curve form and to further refine estimates of site index, the parameters of growth curves for fixed levels of site index were examined in relation to stand density, geographic location, and a number of topographic features. Although the relationship between growth patterns and aspect, slope position, and steepness of slope were statistically significant, the improvement in estimation of site index was small. The additional accuracy did not warrant including these topographic features in a practical scheme for estimating site index. A particular effort was made to explore the effect of stand density on site index; however, no significant association between height growth and stand density was observed.

Precision of the Curves

To measure precision of the site index curves generated by equation 4, estimates of site index at age 10, 15, 20, and 30 years were made from total height of the 42 sample stands. Estimates were then compared to actual site index of the stands. These comparisons are summarized in table 1.

As is to be expected with any set of site curves, the estimates become more precise as stand age approaches index age. At age 30, all the estimates are within 10 feet of actual site index, but at 10 years 71 percent of the estimates are within 10 feet of actual site index and 8 percent err by 25 feet or more. There was no evidence of bias at any age, and the accuracy expected in even the 10-year-old stands is probably sufficient for most management purposes.

Table 1.—Deviations of estimated site index from actual site index

Deviations	10 years		15 years		20 years		30 years	
	Stands	Cumulative percentage	Stands	Cumulative percentage	Stands	Cumulative percentage	Stands	Cumulative percentage
	Number		*Number*		*Number*		*Number*	
Within ± 5 feet	16	38	19	45	27	64	37	88
Within ± 10 feet	14	71	14	78	12	93	5	100
Within ± 15 feet	6	85	7	95	2	97	----	----
Within ± 20 feet	3	92	1	98	1	100	----	----
Within ± 25 feet	3	100	1	100	----	—	----	----
Total	42		42		42		42	

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wind resistance

OF STRESSED-SKIN CURTAIN-WALL PANELS BONDED WITH ELASTOMERIC ADHESIVES

by Charles B. Vick · D. C. Wittenberg

USDA Forest Service Research Paper SE-81 • April 1971

Wind Resistance of Stressed-Skin Curtain-Wall Panels Bonded with Elastomeric Adhesives

by

C. B. Vick, Wood Scientist
and
D. C. Wittenberg, Associate Architect

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Athens, Georgia

INTRODUCTION

One of the objectives of the Housing Research Project at the Forestry Sciences Laboratory in Athens, Georgia, is to improve the structural and economic efficiency of wood used in house construction—particularly rural low-cost housing. To implement this objective, several structural-design concepts and cost-saving ideas have been incorporated into the plans of six experimental low-cost houses (9). One plan, designated SE-3, features a pole-frame system with stressed-skin panels prefabricated with thin wood components in the nonload-bearing exterior walls. Stressed-skin panels, of course, are not a new development. Rather, their use in this low-cost house represents an attempt to maximize structural strength while reducing the cost of materials. Also, prefabrication of wall panels permits certain economies in construction and installation. For example, stressed-skin panels are simple to construct; they can be assembled quickly in small shops with jigs and a few ordinary carpenter's tools; and they can be installed with a minimum of on-site labor costs.

Adhesives for Consideration

Typically, a rigid, high-strength, and durable adhesive system such as phenol-resorcinol-formaldehyde is used to bond skins to stringers in exterior stressed-skin panels of plywood. High-quality bonds with phenol-resorcinol adhesives can be economically produced in well-equipped shops by mass-production techniques. For the builder with a small shop, however, this adhesive has severe limitations. The adhesive is a two-part system that requires premixing; its pot-life is limited; air temperature must be controlled during spreading, assembly, and curing; both bonding surfaces must be

smoothly surfaced for intimate contact because the adhesive does not fill gaps well; and a pressure of at least 100 pounds per square inch (p.s.i.) must be uniformly applied by clamps, presses, or nails. These requirements are beyond the know-how and capabilities of the average small builder.

A relatively new class of construction adhesives, called elastomerics or mastics, offers a number of advantages over phenol-resorcinol adhesives for prefabrication of stressed-skin wall panels in small shops. In general, these construction adhesives are highly viscous mastics capable of bonding rough, uneven lumber and plywood surfaces with a relatively durable, semi-rigid bond. They are well-suited for field application because they do not require close control of temperature and relative humidity during assembly and cure. They can be extruded easily from 1/10-gallon or 1-quart cartridges with an ordinary caulking gun, or from larger containers with pressurized systems of application. Most important, the adhesive need be applied to only one bonding surface.

Building Code Requirements for Wind Loading

Because the low-cost house for which these particular wall panels were designed is a pole-frame structure, roof loads will be carried by the pole-frame system itself, and not by walls and partitions. Thus, the most significant force remaining on such a nonload-bearing exterior wall is that from wind pressure.

Most building codes demand that exterior walls be built to withstand specified wind loads, but only a few codes specify deflection limitations. The Department of Housing and Urban Development in its "Proposed Minimum Standards for Permanent Low-Cost Housing" (*5*) specifies a minimum of 15 pounds per square foot (p.s.f.) for wind loads on exterior walls in the first story, or a load calculated by multiplying the applicable wind-load value for maximum local conditions by a factor of 0.9. According to this standard, maximum deflection from wind load shall not be more than 1/240 of the span if the interior surface is other than plaster. The wall must sustain two times the specified wind load without failure. Furthermore, it must have a residual deflection of no more than 25 percent after removal of the load.

The Uniform Building Code (*2*) specifies that exterior walls 30 feet or less above ground be designed to withstand wind loads ranging between 15 and 40 p.s.f., with the actual wind load depending upon the average maximum velocity of the wind in that particular geographic location. Although the code does not assign deflection limitations under wind loading, it does set certain construction requirements for interior walls and partitions. Accordingly, walls with nonbrittle finishes must not deflect more than 1/120 of the span.

Other codes such as the Southern Standard Building Code (*8*), the National Building Code (*6*), and the Federal Housing Administration's "Minimum Property Standards for One and Two Living Units" (*4*) specify that exterior walls be built to withstand wind loads less than, or equivalent to, those specified in the Uniform Building Code. None of the above-mentioned codes specify deflection limitations under wind loading, though some local building codes may do so.

Objectives

Elastomeric adhesives appeared to offer certain economies and desirable working characteristics for prefabrication of stressed-skin wall panels of plywood in small shops. It was necessary, however, to determine if these adhesives could perform satisfactorily under anticipated in-service conditions of wind loading. Thus, the primary purpose of this study was to determine if either of two elastomeric adhesives of relatively high strength would impart sufficient bending stiffness to stressed-skin curtain-wall panels of thin wood components so that they would meet the minimum requirement for wind loading specified in recognized building codes. As an additional basis of evaluation, the bending stiffness of stressed-skin panels bonded with elastomeric adhesives was compared with that of similarly constructed panels assembled with: (a) a phenol-resorcinol-formal-

dehyde resin system, which is a standard type of adhesive for such applications; and (b) nails, without any adhesive. No attempt was made in this study to establish engineering-design criteria for such panels bonded with elastomeric adhesives.

EXPERIMENTAL PROCEDURES

Adhesives

Two commercial elastomeric adhesives—one with a rubber base of neoprene and the other with a base of styrene-butadiene—were selected for bonding two groups of stressed-skin wall panels. Both adhesives have relatively high dry-shear strength and water resistance when compared with a number of other elastomerics that have recently been evaluated at this laboratory.

In preliminary tests, the average shear strength of each adhesive was determined from sets of 10 standard block-shear specimens, representative of 10 different adhesive joints, after 28 days of adhesive cure. Block-shear specimens were prepared in accordance with Standard D-905 prepared by the American Society for Testing and Materials (7) with the following exceptions: test-joint assemblies consisted of Douglas-fir plywood laminated to lumber of southern pine (face grain in both laminates was parallel); the controlled thickness of the initial glueline was 0.063 inch; specimens were sheared at a rate of 0.50 inch per minute.

Average shear strengths of specimens when tested dry, wet, and after redrying were as follows:

Adhesive base	Dry[1]	Wet[2]	Wet-redry[3]
		p.s.i.	
Neoprene rubber	503	148	301
Styrene-butadiene rubber	566	237	347

[1] Block-shear specimens at approximately 11-percent moisture content.

[2] Block-shear specimens were tested after a 30-minute vacuum-soak followed by a 4½-hour atmospheric pressure-soak in water at 110° F.

[3] Block-shear specimens were tested after the above water-soak treatment and 48 hours of ovendrying at 110° F.

A third group of wall panels was bonded with a high-strength, waterproof resin system of phenol - resorcinol - formaldehyde designed specifically for lamination of softwood lumber. According to the manufacturer, the adhesive meets performance requirements specified in U.S. Commercial Standard CS-253-63, American Institute of Timber Construction AITC-200-63, the quality-control system of the Plywood Fabricator's Service, and related military specifications. Average initial dry-shear strength of the adhesive was 1,802 p.s.i. with 70-percent wood failure after 28 days of curing under pressure. These values were determined from 14 standard block-shear specimens representative of seven different adhesive joints. Test-joint assemblies were laminated from ¾-inch-thick lumber of southern pine.

Wall Panel Construction

The wall panels were constructed according to the configuration and dimensions illustrated in figure 1. The exterior skins were 4- by 8-foot sheets of Douglas-fir exterior plywood; the 3-ply sheets were channel-grooved and ⅜ inch thick. The interior skins were 4- by 8-foot sheets of prefinished paneling of birch plywood; these sheets, also 3-ply, were ¼ inch thick. Stringers, headers, and blocking were cut from 8-foot-long pieces of 2- by 4-inch construction-grade lumber of white spruce which had been kiln-dried. The two interior stringers were center-ripped from a single 2- by 4-inch piece of lumber, and the two outside stringers were ripped off-center from a single 2- by 4-inch piece. The two headers were 2- by 4-inch nominal dimension. Neither plywood skins nor lumber framework were resurfaced before bonding. Before assembly of the wall panels, all wood materials were conditioned for 2 weeks at approximately 73° F. and 55-percent relative humidity to an average moisture content of 11 percent.

Precut stringers, headers, and blocking were placed in an assembly jig. Each joint was temporarily held together with one ½-inch-deep corrugated fastener until the skins could be bonded and nailed.

Each of two groups of three wall panels was fabricated with one of the two elastomeric

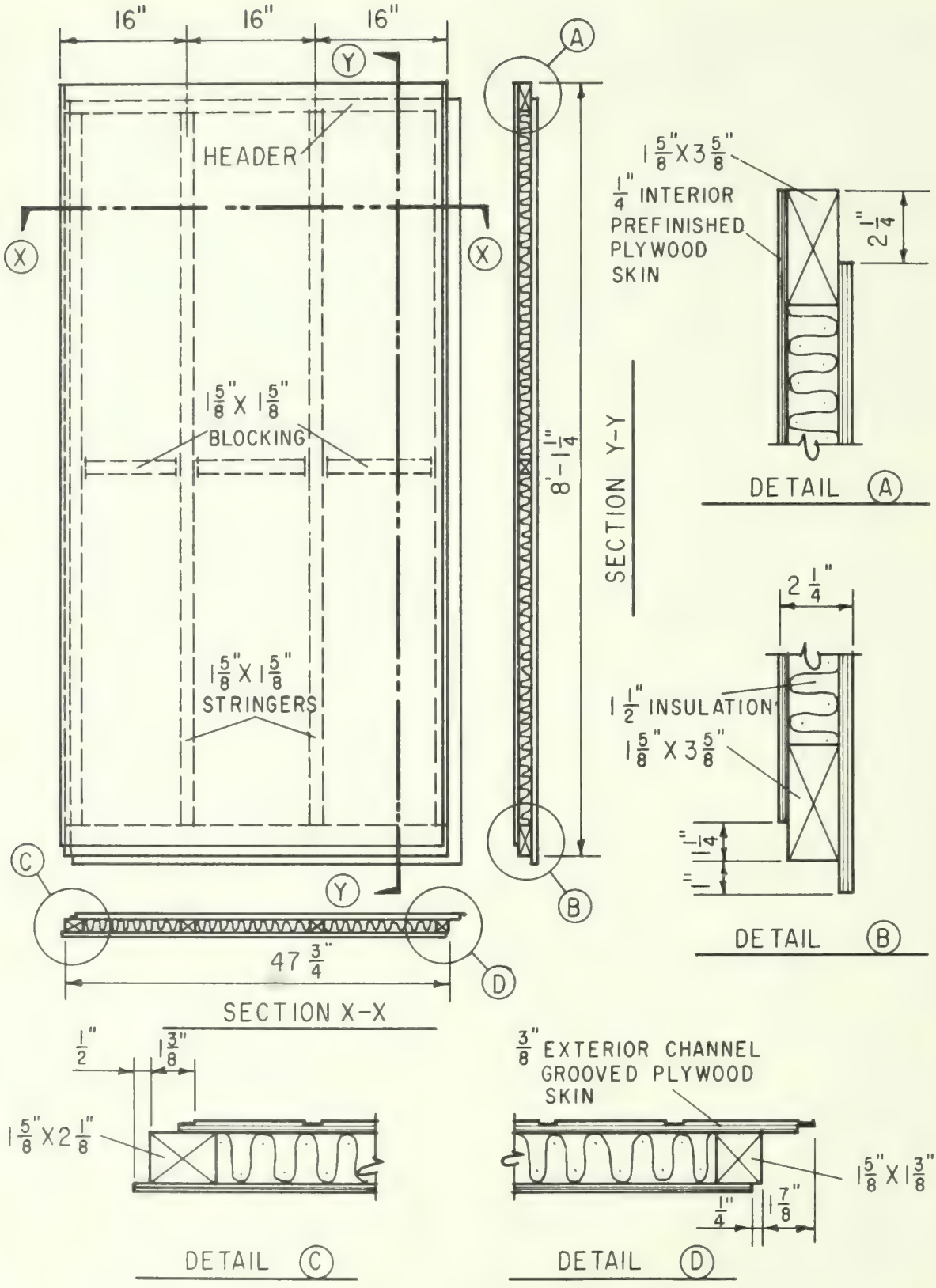

Figure 1.—Construction details of stressed-skin curtain-wall panels 2¼ inches thick.

adhesives. These adhesives were extruded by a caulking gun in a ¼-inch-diameter bead onto both faces of all framing members. No adhesive was applied to the skins. Immediately after the adhesive was spread, exterior skins were fastened to stringers and headers with aluminum common-casing nails (size 4-d.). Interior skins were then fastened with steel common-finishing nails (size 3-d.). The same nail spacing was used on both exterior and interior skins of all adhesive-bonded panels, i.e., five nails spaced 24 inches on-center along each stringer. After bonding, the panels were stacked horizontally and cured for 28 days at approximately 73° F. and 55-percent relative humidity.

A third group of three panels was fabricated with the phenol-resorcinol adhesive and nails. After standing for at least 15 minutes, the adhesive mix was roller-spread on both the lumber framework and the plywood skins of each wall panel. Approximately 10 minutes was required to spread the adhesive on each side of each wall panel. After the adhesive was spread, the skins were immediately placed on the framework and fastened with the same type and size of nails and nail spacing as previously described for the panels bonded with elastomeric adhesives. Finished panels were stacked horizontally and cured for 28 days. Adhesive mixing, spreading, and curing were performed at approximately 73° F. and 55-percent relative humidity.

Approximately 1 quart of elastomeric adhesive was required to single-spread both faces of the framework of each panel—a total of 88 lineal feet. Less than 5 minutes was needed for applying this adhesive to each panel. Approximately the same amount of phenol-resorcinol adhesive was needed to double-spread both sides of each wall panel. (Because the lumber framing was not planed prior to bonding and only a minimum of nailing was used for pressure, the heavy double-spread of phenol-resorcinol adhesive was necessary to establish thick gluelines.) Spreading this adhesive required about 20 minutes—four times the period needed for the elastomeric adhesive.

A fourth group of three wall panels was fabricated with nails without any adhesive. The same types and sizes of nails as previously described were used to fasten exterior and interior skins to stringers. Nail spacing was different, however. Exterior skins were nailed 6 inches on-center along the edge stringers and 8 inches on-center along the interior stringers. Interior skins were nailed 6 inches on-center overall.

Testing Procedures

Tests of transverse (horizontal) loading by the quarter-point loading method were applied to four groups of three stressed-skin wall panels, each group assembled according to one of the following four methods of fastening plywood skins to stringers:

A. Phenol-resorcinol adhesive and nails
B. Neoprene rubber adhesive and nails
C. Styrene-butadiene rubber adhesive and nails
D. Nails without adhesive.

Loads were applied to the exterior faces only.

The testing assembly and apparatus for measuring deflection were set up as shown in figure 2. The entire testing assembly was supported on two 8-inch steel beams with flanges 5¼ inches wide; the beams rested firmly on a 6-inch-thick floor of reinforced concrete. Free-moving steel roller-bars and plates were center-positioned atop each beam to support the test panels. These supports were adjusted so that the panels could be tested as a simple beam over a span of 7½ feet.

The loading assembly consisted of calibrated lead weights uniformly distributed over a platform 3½ feet wide and 4 feet long. The platform was suspended by cables from an overhead hoist. When lowered, the weighted platform rested on two, free-moving roller-bars and plates which were centered over the two quarter points of the 7½-foot span.

The test panels were instrumented with two 2-inch dial micrometers which recorded deflections to the nearest 0.001 inch. These micrometers were firmly supported from the floor and cantilevered over both sides of the

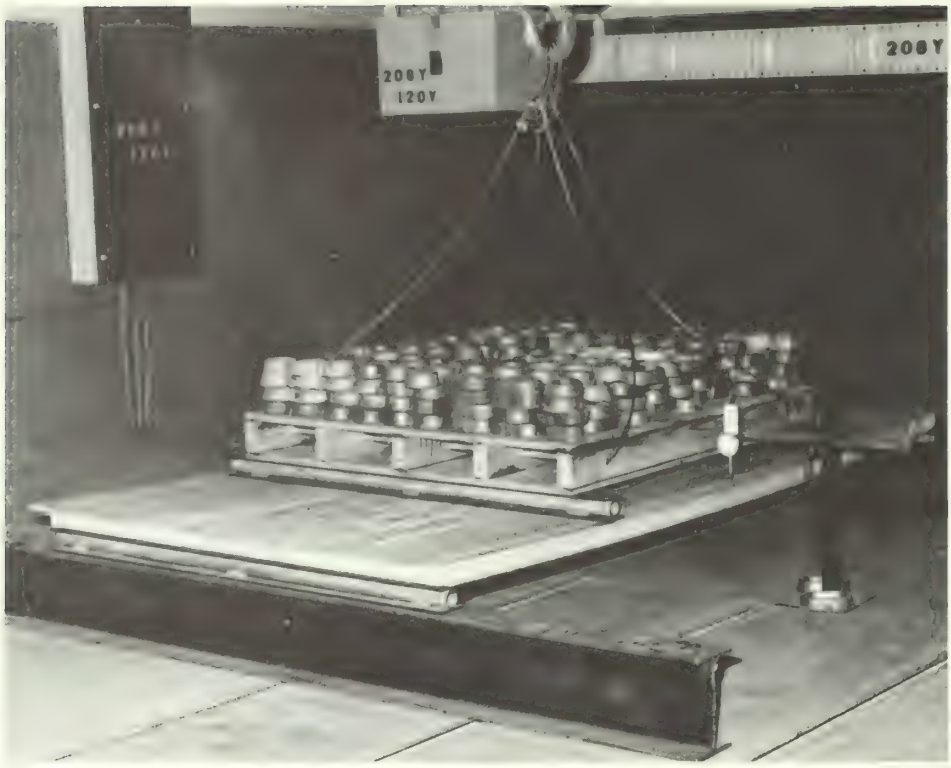

Figure 2.—Supporting and loading assemblies and apparatus for measuring deflection used in testing the resistance of wall panels to simulated wind loads.

panel at midpoint of the span. Usually, dial gages are mounted on a suitable reference bar on the test panel and deflections are measured from fixed reference points on the panel. This arrangement is intended to avoid errors in deflection measurements caused by settlement of supports under loading. A check of such settlement of the support system in the present tests showed an average maximum of 0.010 inch under a load of 100 p.s.f. Because settlement was negligible, it was ignored in deflection measurements.

The test panels were loaded in increments of 10 p.s.f. up to 100 p.s.f. or to the point at which the behavior of the panel (such as cracking sounds) indicated that sudden failure might occur with an additional increment. The zero reading on the test panel was taken with an initial load of 4.5 p.s.f., which included the dead weight of the test panel itself (75 pounds) plus the weight of the two steel roller-bars and plates (60 pounds). Additional weights were used to increase the first increment to the prescribed load of 10 p.s.f. Each test load was lowered to rest at a rate of approximately 1 inch per minute. Once loads were at rest, a 2-minute time lapse was allowed before deflections were read. Then loads were removed; another 2-minute time lapse was allowed; and deflections were read again to determine permanent set. After each increment was added, load-deflection and permanent set were calculated as the average of the deflections (less initial deflection readings) obtained from the two micrometers.

RESULTS AND DISCUSSION

Actual mid-span deflections under loading, as well as permanent set (residual deformation), are plotted for the individual test panels in figures 3 through 6. Maximum applied loads, loads at the proportional limits, and ratios of load to deflection for the linear portions

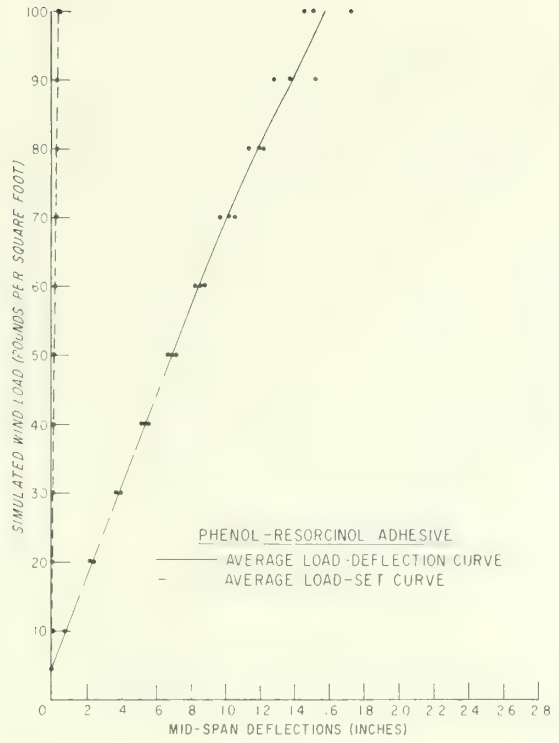

Figure 3.—Mid-span load-deflection and load-set curves for three test panels bonded with a phenol-resorcinol adhesive.

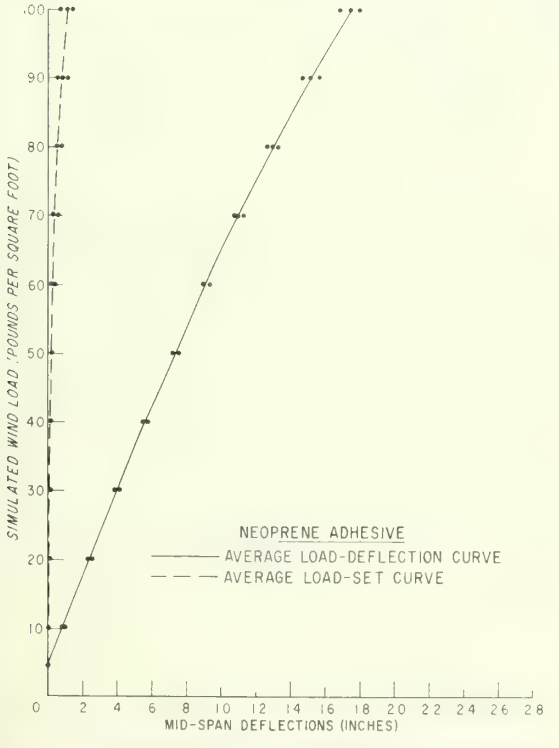

Figure 4.—Mid-span load-deflection and load-set curves for three test panels bonded with a neoprene rubber adhesive.

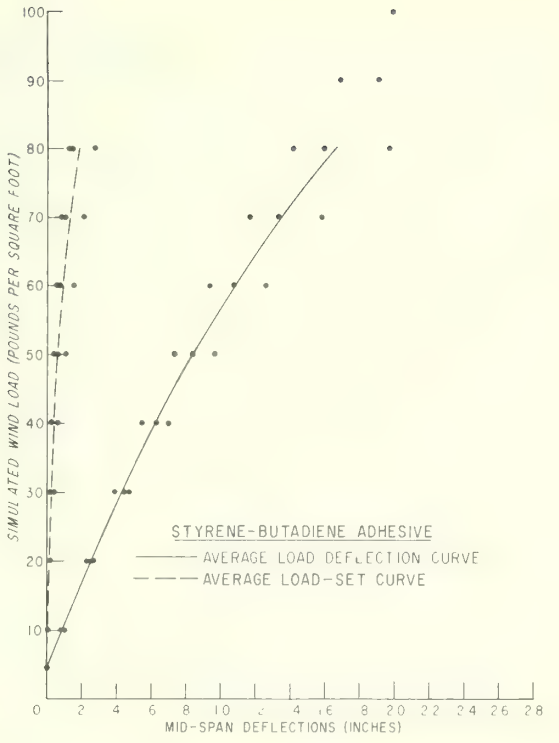

Figure 5.—Mid-span load-deflection and load-set curves for three test panels bonded with a styrene-butadiene rubber adhesive.

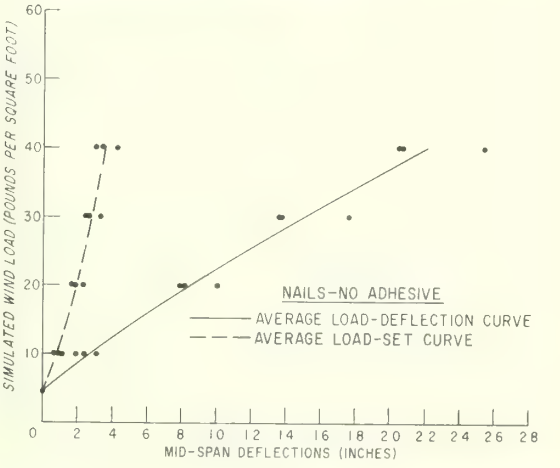

Figure 6.—Mid-span load-deflection and load-set curves for three test panels which were nailed without any adhesive.

of the curves were determined directly from the load-deflection curves of individual test panels (figures 3 through 6) and are shown in table 1. Load-deflection ratios, which describe the slopes of the straight-line portions of curves, were used to calculate the apparent

Table 1.—Results of simulated wind-loading tests on 2¼-inch-thick panels assembled with various types of joints

Type of joint	Test panel number	Maximum applied load	Load at proportional limit	Load-deflection ratio	Apparent bending stiffness	Calculated load at limiting deflections[1]		
						1/240 of span (0.405 inch)	1/180 of span (0.540 inch)	1/120 of span (0.810 inch)
		Lb./sq. ft.		*Lb./sq. ft./in.*	*10⁶ lb.–sq. in.*	*Lb./sq. ft.*		
Phenol-resorcinol adhesive	1	100	60	64.9	20.3	21.5	28.6	42.9
	2	100	60	63.2	19.8	20.9	27.9	41.9
	3	100	70	67.5	21.1	22.3	29.7	44.6
	Average	....	....	65.2	20.4	21.6	28.8	43.1
Neoprene rubber adhesive	1	100	70	61.1	19.1	20.2	26.9	40.4
	2	100	60	60.5	19.0	20.1	26.8	40.2
	3	100	60	62.5	19.6	20.7	27.6	41.4
	Average	....	....	61.5	19.3	20.4	27.2	40.8
Styrene-butadiene adhesive	1	80	30	55.8	17.5	18.5	24.7	37.0
	2	90	40	56.7	17.8	18.8	25.1	37.6
	3	100	40	65.0	20.4	21.6	28.8	43.1
	Average	....	....	59.2	18.5	19.6	26.1	39.1
Nailed without adhesive	1	40	30	18.7	5.9	6.2	8.3	12.5
	2	40	30	17.4	5.5	5.8	7.8	11.6
	3	40	20	14.0	4.4	4.7	6.2	9.3
	Average	....	....	16.7	5.2	5.5	7.3	11.0

[1]If uniformly distributed over a span of 8 feet 1¼ inches.

bending stiffness (EI, or modules of elasticity multiplied by moment of inertia) of the composite panels. Values of bending stiffness for the various panels were calculated from the standard deflection formula for a simple beam with two equally concentrated loads symmetrically placed (quarter-point loading) and acting over a span of 7½ feet (*3*). Because no single deflection requirement was common to all recognized building codes, three typical limiting deflections were assumed. Loads were computed at each of these limiting deflections for each test panel. These loads are shown in the last three columns of table 1. They were calculated from the standard deflection formula for a simple beam with a uniformly distributed load acting over a span of 8 feet 1¼ inches (the full length of the test panels) (*3*).

As expected, stressed-skin panels fabricated with the more rigid phenol-resorcinol adhesive were stiffer than those joined with elastomeric adhesives or nails. This relationship can be seen by comparing the average values of bending stiffness for all four groups of panels listed in table 1. However, if the panels bonded with phenol-resorcinol are used as the standard of comparison, those bonded with neoprene were about 95 percent as stiff, those bonded with styrene-butadiene were about 91 percent as stiff, and those that were nailed without adhesives were only about 25 percent as stiff.

All panels bonded with phenol-resorcinol and neoprene adhesives were capable of resisting simulated wind loads of 100 p.s.f. without failure. This load was equivalent to a wind

force of 173 miles per hour on a typical rectangular house with a gabled roof and vertical walls perpendicular to the wind direction.[4] Among the panels within these two groups, the lowest value for the proportional limit was 60 p.s.f. (equivalent to a wind velocity of 134 m.p.h.). Obviously, these panels have both ample initial strength and resistance to permanent damage at very high wind loads. However, limiting deflections such as those shown in the column headings of table 1 may be imposed by either local building codes or a few regional codes. For example, HUD's "Proposed Minimum Standards for Permanent Low-Cost Housing" (*5*) limits deflections to 1/240 of the span (0.405 inch for the panel with a span of 8 feet 1¼ inches) for walls with nonbrittle finishes. Thus, according to computed values in table 1, wall panels of this construction and bonded with neoprene or phenol-resorcinol adhesive will be restricted to geographical areas where wind loads do not exceed 20 p.s.f. or wind velocities of 77 m.p.h. If a deflection limitation of 1/120 of the span (0.810 inch for the span of 8 feet 1¼ inches) were applied, such as by the Uniform Building Code (*2*), then these panels could be used in those areas of the country with the most intense windstorms; in such areas, minimum wind loads of 40 p.s.f. (equivalent to a wind velocity of 110 m.p.h.) are required.

Although the average bending stiffness calculated for the three panels bonded with styrene-butadiene was about 91 percent of that for the panels bonded with phenol-resorcinol, the lowest value for the proportional limit among the three test panels was 30 p.s.f., or half that for the panels bonded with phenol-resorcinol. The lower bending stiffness was also reflected in the lower values for maximum applied wind loads—80, 90, and 100 p.s.f. (table 1). Even so, panels bonded with styrene-butadiene adhesive could resist severe windstorms of 155 m.p.h. (equivalent to a load of 80 p.s.f.) without failure. At a deflection limitation of 1/240 of the span, the maximum wind load would be 15 p.s.f., equivalent to a wind velocity of 67 m.p.h.; at a deflection limitation of 1/180 of the span, the maximum wind load would be 20 p.s.f., equivalent to a wind velocity of 77 m.p.h.; and at a deflection limitation of 1/120 of the span, the maximum wind load would be 35 p.s.f., equivalent to a wind velocity of 101 m.p.h. (table 1).

The nailed panels without adhesive were weak in comparison with those bonded with adhesives. They withstood simulated wind loads of 40 p.s.f. without failure, and the lowest value for the proportional limit among the three panels was 20 p.s.f. Deflections were so excessive that none of these panels could meet a minimum wind load of 15 p.s.f. at any of the deflections shown in table 1.

HUD's "Proposed Minimum Standards for Permanent Low-Cost Housing" (*5*) is the only cited building code that specifies limits on permanent set in walls under wind loading. That limit is 25 percent of 1/240 of the span, or 0.101 inch over the span of 8 feet 1¼ inches. As can be seen from figures 3 through 6, permanent set was not a limiting factor in restricting the use of any test panels. Specified deflections were always limiting.

Figures 3, 4, 5, and 6 show the variations in deflection readings among the three individual test panels within each group. At loads of 100 p.s.f., the range in deflection of the panels bonded with phenol-resorcinol was 0.281 inch (fig. 3), and that of the panels bonded with neoprene was 0.120 inch (fig. 4). The close dispersion of deflection values among the panels bonded with neoprene is noteworthy in comparison with the ranges in deflections of the other groups of test panels. The largest range in deflections occurred in the three panels bonded with styrene-butadiene—0.552 inch at loads of 80 p.s.f. There was also variability in the ultimate load levels with this adhesive as shown in figure 5: panels 1, 2, and 3 withstood loads of 80, 90, and 100 p.s.f. The nailed panels also showed a large range in deflections—0.490 inch at loads of 40 p.s.f. (fig. 6).

[4] Wind velocities were calculated from the basic equation for wind force: $q = 0.002558\ V^2$, where V is velocity in miles per hour, and q is dynamic pressure in pounds per square foot. The average of the total combined pressure was obtained by multiplying q by a shape coefficient of 1.3 (*1*).

Variability in deflections of test panels within a group under a given load cannot be accounted for except in general terms. Several factors could significantly affect the stiffness of individual panels: variations in the bending stiffness of wood as influenced by the location and number of knots and other such characteristics, and variations in the parameters associated with the bonding. Such variations, however, are common to almost all accepted types of wall constructions.

CONCLUSIONS

Tests involving simulated wind loading show that stressed-skin curtain-wall panels fabricated with thin, low-cost wood components and two relatively high-strength elastomeric adhesives were over 90 percent as stiff as similarly constructed panels that were bonded with a rigid phenol-resorcinol resin adhesive. Wall panels bonded with the two elastomeric adhesives could resist at least two times the minimum wind load of 40 p.s.f. (equivalent to a wind velocity of 155 m.p.h.) specified in recognized building codes for the areas of severest windstorms in the United States. Permanent set, which might be presumed to be objectionable with the elastomeric adhesives, was not found to be a significant factor. Some building codes specify maximum deflections for exterior walls under wind loading. Under rigid requirements for deflection, thin wall panels bonded with elastomeric adhesives might be restricted from areas subject to high-intensity windstorms along the Atlantic seaboard and gulf coast. For the most part, however, these wall panels will be suitable for more than 90 percent of the land area in the United States.

Elastomeric adhesives possess certain working characteristics and time-saving feaures that make them particularly suitable for prefabrication of stressed-skin curtain-wall panels for low-cost housing. Such prefabrication can be accomplished in small shops. As the performance tests indicate, these high-quality elastomeric adhesives have sufficient short-term strength to withstand most wind-loading requirements specified in cited building codes. It should be recognized, however, that elastomerics are a relatively new class of adhesives. For this reason, their resistance to deterioration under long-term natural aging has not been fully evaluated. Extrapolation of data on accelerated and natural aging by people in the rubber industry indicates that high-quality adhesives properly formulated for durability should remain serviceable for at least 20 years. Until long-term natural aging can be fully studied, short-term strength tests and guidelines on accelerated aging as developed by the rubber industry should be used to eliminate adhesives that deteriorate rapidly.

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Prefabricated stressed-skin panels have been used in designs for low-cost housing. Elastomeric adhesives offer advantages for bonding these plywood panels, but wind resistance after such bonding has not been determined. Accordingly, we applied simulated wind loads to curtain-wall panels made of thin wood components bonded with either of two elastomeric adhesives. These tests showed such panels have ample strength to resist the severest of windstorms without failure. These adhesives also have working characteristics that make them particularly well-suited for the prefabrication of stressed-skin panels in small shops.

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U.S. Department of Agriculture
Forest Service
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by

Ralph H. Hughes
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In 1963, a study on forest fertilization was established in an old-field plantation of slash pine *(Pinus elliottii* var. *elliottii)* near Olustee, Florida. High yields of desirable forage species resulted after the plantation received a single application of fertilizer. The responding species, mostly grasses relished by livestock and of importance to wildlife, were relicts of the old-field vegetation. These yields are reported in terms of ovendry weight per acre for the 4-year period that followed the fertilizer application.

STUDY AREA

The study area was a moderately well-stocked, old-field plantation containing 136 trees per acre and a mean basal area of 71 sq. ft. Trees were pole- and saw log-sized and averaged 10 inches d.b.h., with heights ranging from 80 to 95 ft. Height to the base of live crown varied from 30 to 50 ft.

The soil was predominantly Leon fine sand. This moderately deep, acid, sandy soil, with low organic content and natural fertility, occurs on nearly level, moderately wet land throughout the Lower Coastal Plain of the southeastern United States. Textural analysis of the upper 6 inches revealed 95-percent sand, 3.5-percent silt, and 1.5-percent clay, with pH varying from 4.3 to 4.7. Prior to fertilization, total nitrogen (N) content in soil samples varied from 1,500 to 2,500 lb. per acre and available phosphorus (P) from 10 to 45 lb. (according to the Bray No. 2 procedure). In 3 of the 4 years, May to October rainfall exceeded the 33-inch long-term mean, with 29 inches in 1963, 48 inches

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in 1964, 42 inches in 1965, and 41 inches in 1966.

A light cover of herbaceous vegetation was present throughout the plantation at the start of the experiment. Common carpetgrass (*Axonopus affinis* Chase) and broomsedge (*Andropogon virginicus* L.) were the main grasses. Other common grasses were big bluestem (*Andropogon gerardi* Vitman) and creeping bluestem (*A. stolonifer* (Nash) Hitchc.), several panicums including warty panicum (*Panicum verrucosum* Muhl.) and hairy panicum (*P. rhizomatum* Hitchc. and Chase), and bull paspalum (*Paspalum boscianum* Flügge). Elephantsfoot (*Elephantopus tomentosus* L.) and poor-joe (*Diodia teres* Walt.) were common forbs. Low shrubs, mostly sand blackberry (*Rubus cuneifolius* Pursh) and gallberry (*Ilex glabra* (L.) Gray), were widespread, normally occurring in patches.

PROCEDURE

The study area was prescribed burned and divided into ¾-acre plots during the week of April 8, 1963, just prior to the application of fertilizers. These were applied in swaths between rows of trees in a north-south direction with a drill-type spreader (fig. 1). Current growth of the understory vegetation was obtained on 9.6-sq.-ft. quadrats. Each winter thereafter, all understory vegetation was clipped to a height of 3 to 4 inches with a rotary mower. Fire and grazing were excluded during the course of the study, but there was evidence of controlled burning and grazing in earlier years.

Fertilization consisted of three levels of N and two levels of P. Rates applicable to the treated area between rows of trees were 0, 100, and 200 lb. of N per acre and 0 and 44 lb. of P per acre. Treatments were replicated three

Figure 1.—Fertilizer application in the old-field plantation in April 1963. The fertilizer is being applied in swaths between rows of trees.

times in a factorial design with randomized blocks. Sources of N and P were ammonium nitrate (33-percent) and superphosphate (8.8-percent). Approximately half the area was in unfertilized areas occupied by rows of trees.

Estimates of herbage yield and ground cover were obtained by clipping three quadrats on each plot to a 1-inch stubble. Ovendry weights were obtained separately for important species and groups. Visual estimates were made of the percentage of ground surface covered by the foliage of each species. Swaths in rows and between rows of trees were inventoried the first year; only the swaths between rows of trees were inventoried thereafter.

RESULTS

Single applications of three fertilizer treatments (200 lb. of N and no P, 100 lb. of N plus 44 lb. of P, and 200 lb. of N plus 44 lb. of P) in April 1963 produced highly significant increases in herbage yields the first year (fig. 2). Only at the highest fertilization level (200 lb. of N plus 44 lb. of P) did the increase carry over into the second year. This high rate of fertilization increased production more than fivefold the first year (2,800 vs. 500 lb. per acre) and nearly twofold (1,500 vs. 900 lb. per acre) the second year. Although the main effect of N was to increase herbage production, N was not effective at the lowest level (100 lb.) without P, and 44 lb. of P had no influence alone. No fertilizer treatments affected herbage yields the third or fourth year.

Species response the first year was characterized by increased growth of grasses (fig. 3). On the average, grasses comprised 80 percent of the harvests on swaths fertilized with N and only 50 percent on unfertilized swaths. The grasses furnished more than 90 percent of the gain in yield, of which about half was by the bluestem grasses—primarily broomsedge, big bluestem, and creeping bluestem. Despite wide distribution of carpetgrass throughout the plantation, its yield was not determined separately because of its low growth form.

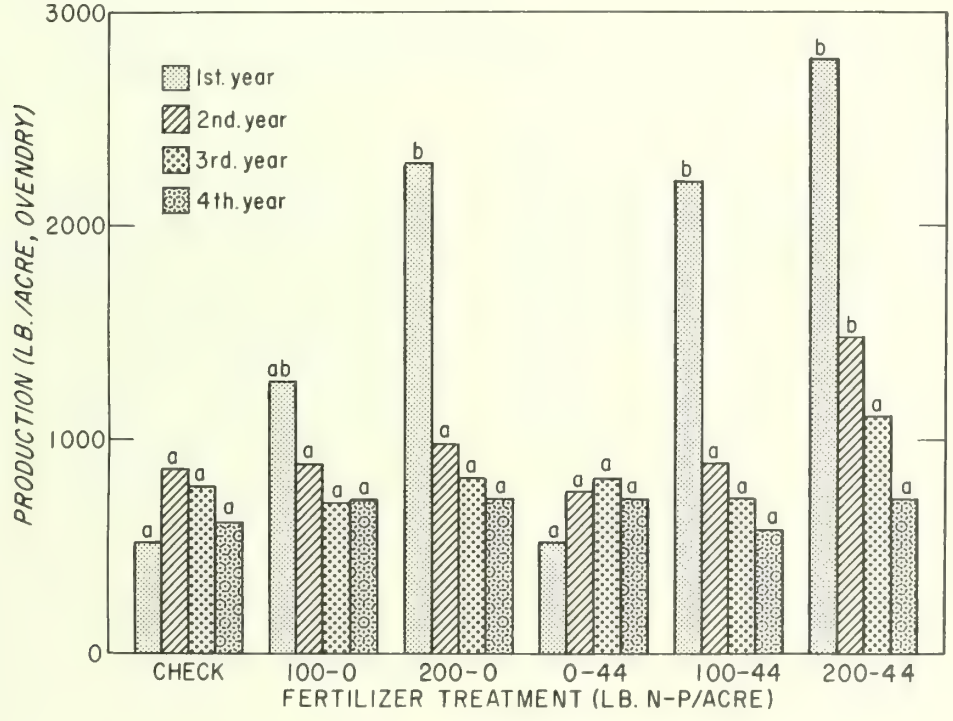

Figure 2.—Annual production of herbaceous vegetation after the fertilizer treatments in April 1963. Bars not labeled with the same letter are significantly different at the 5-percent level.

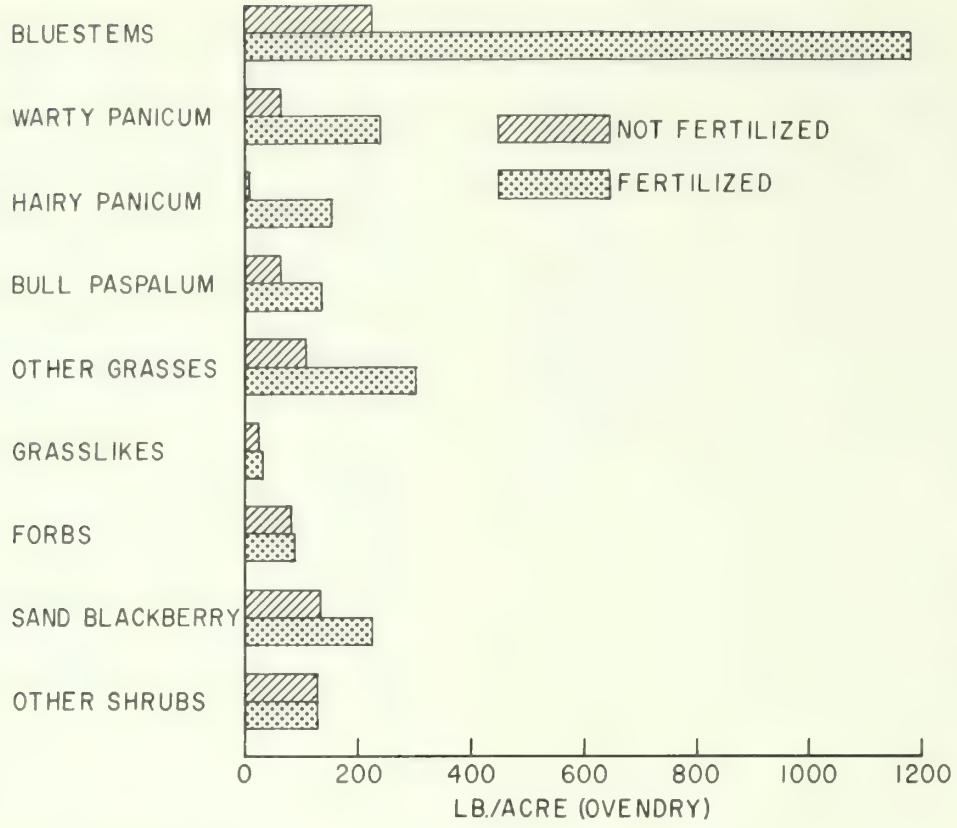

Figure 3.—Composition of understory vegetation clipped the first year from quadrats in unfertilized plots and those fertilized with N. (Average of the following treatments: 100 lb. of N and no P, 200 lb. of N and no P, 100 lb. of N plus 44 lb. of P, and 200 lb. of N plus 44 lb. of P.)

On quadrats where it occurred, sand blackberry appeared to respond to fertilizer. Other shrubs, forbs (including legumes), and grasslikes were encountered in lesser amounts and averaged about the same on fertilized and unfertilized swaths.

Response the second year after the application of fertilizer was limited to increased production of the bluestem grasses in the most heavily fertilized treatment. Yields were 730 lb. per acre in quadrats fertilized with 200 lb. of N plus 44 lb. of P and 240 lb. per acre in the unfertilized quadrats.

Visual estimates of the ground cover also reflected the response to fertilizers containing N (100 lb. of N and no P, 200 lb. of N and no P, 100 lb. of N plus 44 lb. of P, and 200 lb. of N plus 44 lb. of P). When grouped together, grasses other than carpetgrass displayed a strong response (fig. 4). Carpetgrass did not respond to fertilization under conditions of this study, but it did maintain its cover beneath the taller growing bunchgrasses throughout the 4-year period of the study.

The clipped herbage contained several plants important as game food. Taken together, panicum and paspalum grasses increased from 180 lb. per acre when no N was applied to 210 lb. per acre when N was applied at the 100-lb. rate to 860 lb. per acre when N was applied at the 200-lb. rate. These grass species are considered to be preferred foods for quail and turkey and emergency food for deer in the slash-longleaf flatwoods of north Florida and south Georgia (Ripley et al. 1965). Bluestem grasses are rated as emergency food for quail, turkey, and deer, and blackberries are rated as

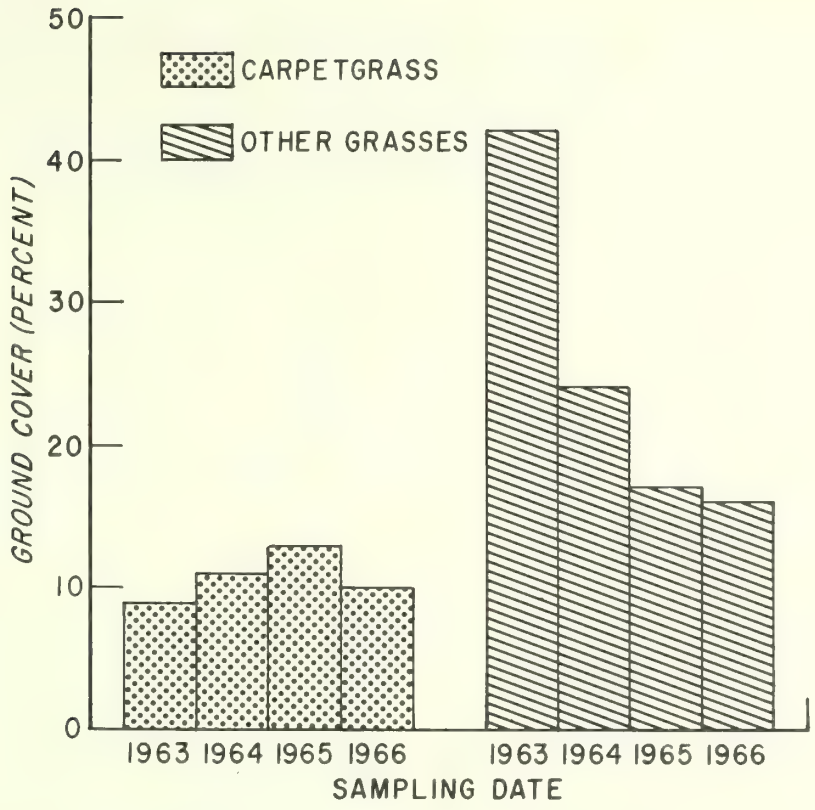

Figure 4.—Visual estimates of ground cover by carpetgrass and other grasses on swaths receiving N fertilization in 1963.

staple food for turkey and deer and emergency food for quail.

Carpetgrass was not harvested separately because of its limited production above the 1-inch clipping height. This species is closely grazed by cattle, and, in a study with penned quail, its seeds were sufficiently utilized to warrant its use in permanent food plantings (Michael and Beckwith 1955). Legumes occurred only sparingly throughout the plantation, and no response was detected. During the course of the study, volunteer seedlings of Pensacola bahiagrass (*Paspalum notatum* Flügge), absent in the initial inventory, appeared as scattered plants throughout the plantation.

When taken for chemical analysis in late September 1963, total herbage samples from swaths receiving N alone contained significantly less crude protein than did herbage from swaths receiving P alone (table 1). In fact, crude protein and phosphorus averaged less in swaths receiving N alone than in swaths in unfertilized plots. Apparently, N fertilization stimulated stemmy growth, which by fall contained less protein per unit of dry matter than did unfertilized growth. When N and P were applied together, the tendency toward stemmy growth was reduced and protein and phosphorus levels remained similar to those on unfertilized plots.

In broomsedge, which was sampled separately, crude protein was not strongly affected by any of the fertilization treatments. Phosphorus contents were similar to those in the total herbage samples noted above. Had samples of total herbage and broomsedge been taken earlier in the season, crude protein and phosphorus levels would likely have been higher. Nitrogen values are usually highest in the spring and then generally decline as plants mature (Koelling and Kucera 1965).

Table 1.—Crude protein and phosphorus content of total herbage and broomsedge grass in each fertilizer treatment during September 1963

Treatment		Total herbage		Broomsedge grass	
N	P	Crude protein	Phosphorus	Crude protein	Phosphorus
Lb./acre		*Percent*[1]			
0	0	4.4 ab	0.11 ab	3.3 ab	0.11 bc
100	0	3.8 a	.07 a	3.1 ab	.08 ab
200	0	3.7 a	.07 a	3.3 ab	.07 a
0	44	4.7 b	.12 ab	2.9 a	.12 c
100	44	4.3 ab	.13 b	3.3 ab	.11 bc
200	44	4.4 ab	.13 b	3.5 b	.10 abc

[1]Values within a column followed by the same letters are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

DISCUSSION

The results suggest that with fertilization a plantation suitably stocked for timber production can also be made to produce a significant amount of forage. Yields of indigenous herbage in this old-field plantation increased 500 to 1,000 lb. with each 100-lb. increase in the N level, results which compare favorably with yields of improved forage species beneath pine (Hart et al. 1970).

Not all pine plantations could be expected to show such good results. Beneath heavier stands (basal areas of 85 sq. ft. per acre) of slash pine planted on cutover lands in central Louisiana, Duvall and Grelen (1967) reported that forage responded much less favorably to fertilization. However, old-field sites are generally superior to cutover lands for forest growth (Bennett 1956); perhaps some of the factors that promote forest growth on old fields also make for better forage growth when these sites are fertilized.

Conditions within the plantation would seem to favor the introduction of improved forage species. The appearance of Pensacola bahiagrass came as no surprise because this desirable forage species is an aggressive, shade-tolerant grass that will grow over a wide range of soil conditions (Stephens and Marchant 1960). It spreads readily by seed and is widely distributed in its area of climatic adaptation (Beaty et al. 1960).

However, the rapid decline in response shows that, if old-field plantations of low N status are expected to produce an abundance of food for livestock and game, available N probably should be provided at rather short intervals, annually or at most every 2 years. The desirable forage grasses grew abundantly while soluble N and P were available during the first year after fertilization. As the fertilizer leached out of the soil or became unavailable, the grasses declined because they had to rely on nutrients recycled from cast needles of the pines and from other organic sources. Pines, however, seem to derive longer lasting benefits from N fertilization (Hoekstra and Asher 1962).

No realistic measure of herbage quality during the growing season was obtained. Crude-protein content of the mature herbage was somewhat lower than levels reported from improved pasture (Kretschmer and Hayslip 1963) or native range (Hilmon and Lewis 1962) at the same time of year. Nevertheless, in a nearby grazed replicate of the present study, utilization of fertilized plots by cattle approached 100 percent.

In this particular plantation, none of the treatments produced a sufficient increase in volume of merchantable wood to justify the application of these fertilizers at the rates investigated.

If it is assumed that the only positive response to fertilization was made by the forage

component when fertilized with 200 lb. of N plus 44 lb. of P, the per-acre cost of fertilizer and application at current (1970) prices would be $32. With a return of 2,250 lb. of additional herbage (dry weight) the first year and 600 lb. the second year, the increased yields cost $22 per ton of dry herbage.

It seems clear, on the basis of these results, that utilization of forage resulting from fertilization of certain pine-forest ecosystems can bear a significant share of the costs of such a practice and, therefore, might tip the balance toward profitability of the operation.

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1971. Forage Response to Nitrogen and Phosphorus Fertilization in a 25-Year-Old Plantation of Slash Pine. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SE-82, 7 pp.

In a 25-year-old plantation of slash pine near Olustee, Florida, a single application of 200 lb. of nitrogen and 44 lb. of phosphorus per acre increased production of herbaceous understory (primarily native bluestem grasses) to more than a ton per acre the first year, a fivefold increase. Production declined sharply the second year, and the response disappeared in the third.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

Forest Service, U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

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STUMP SPROUTING AFTER HARVEST CUTTING IN SWAMP TUPELO

by

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AUG 5 1971

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STUMP SPROUTING AFTER HARVEST CUTTING IN SWAMP TUPELO[1]

by

Dean S. DeBell, Associate Plant Physiologist
Charleston, South Carolina

Stump sprouting of swamp tupelo (Nyssa sylvatica var. biflora (Walt.) Sarg.) is known to occur in young trees.[2] A recent study has shown that seedlings will also sprout after cutting and that this sprouting is affected by stump height.[3] Whether mature trees will also sprout, however, has not been recorded in the literature. Because sprout reproduction is an important consideration in making prescriptions for regenerating tupelo swamps, a study was established in a mature stand of swamp tupelo to evaluate effects of several factors that might influence sprouting, including stump height, other stump-size characteristics, residual stand stocking, and year of harvest cutting. This paper reports on sprout production of mature swamp tupelo one growing season after harvest cut.

METHODS

The study was imposed on plots installed for a comprehensive study of natural regeneration in Bluebird Swamp, a headwater swamp on the Francis Marion National Forest, Berkeley County, South Carolina. The timber is nearly pure, even-aged (about 90 years old) swamp tupelo with a scattering of baldcypress and red maple. Prior to harvest, an average acre contained 245 stems 5 inches d.b.h. and larger, 168 square feet of basal area, and 24 M b.m. (Scribner Rule) of sawtimber. The main study

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[1] This study was a cooperative effort with Francis Marion National Forest, the Williams Furniture Company (now a subsidiary of Georgia-Pacific Corporation), and the Southeastern Forest Experiment Station.

[2] Fowells, H. A. Black tupelo (Nyssa sylvatica Marsh.), pp. 278-280. In Silvics of forest trees of the United States. USDA Forest Serv. Agr. Handbook 271. 1965.

[3] Hook, D. D., and DeBell, D. S. Factors influencing stump sprouting of swamp and water tupelo seedlings. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SE-57, 9 pp. 1970.

plots were 7 chains square (4.9 acres), and each received one of four harvest cuts: a clearcut or partial cuts with 15, 30, or 90 trees left per acre. Each type of cut was replicated three times. Replicate blocks were cut during the dormant season (December-March) of three successive years: 1965-66, 1966-67, 1967-68.

Two adjacent subplots (0.1 acre each) and a surrounding isolation zone (0.5 chain wide) were established within each main plot. On one subplot the stumps were cut high, and on the other the stumps were cut low. High-cut stumps were accepted as ordinarily cut by loggers (fig. 1) and averaged 25 inches high (range 13 to 50 inches). Low-cut stumps were established by recutting the stumps on one subplot as low as practicable soon after logging was completed. These stumps averaged 6 inches high (range 3 to 11 inches). Diameter at 16 inches above the ground, cut-surface diameter, and height were measured for each stump. After the first growing season, each stump was measured for number of sprouts, aggregate length of sprouts, and height of the tallest sprout. These data were summarized for each subplot. Summaries were also made of the percentage of stumps having one or more sprouts and the average height of sprouts.

Figure 1.--This clearcut plot was harvested in the winter of 1968. Swamp tupelo stumps are usually cut high (average 25 inches) by loggers.

First-year differences in sprout production by stump height (high vs. low), residual stand stocking (0, 15, 30, and 90 trees per acre), and year of harvest were tested by analysis of variance. Also, the relationships between sprouting and characteristics of individual stumps (height, cut-surface diameter, and diameter at 16 inches above ground) were examined by regression techniques.

RESULTS AND DISCUSSION

Stump height had a significant effect upon number of sprouts per stump, aggregate sprout length, and percentage of stumps having one or more sprouts (table 1). After one growing season, 63 percent of the high-cut stumps and only 13 percent of the low-cut stumps had stump sprouts (fig. 2). No root sprouts were produced on any of the root systems of the high- or low-cut stumps. Because stump height did not affect average sprout height or height of the tallest sprout, the differences in aggregate sprout length resulted primarily from differences in the number of sprouts produced and not from differing growth rates in the first year. Year of harvest, residual stand stocking, and the interaction between stump height and stocking had no significant effect on any sprouting variable, although stocking may influence the growth of sprouts in subsequent years. Such growth will be dependent on current photosynthate and, hence, could be affected by differences in shading and competition.

Table 1.--Average values for sprouting variables analyzed and significance of stump height on sprouting

Stump height	Sprouting variable[1]				
	Sprouts	Aggregate sprout length	Stumps sprouting	Average sprout height	Height of tallest sprout
	Number/stump	Feet	Percent	Feet	Feet
High	3.6	8.4	63	2.3	3.2
Low	.5	1.2	13	2.4	3.1
Level of significance	1%	1%	5%	NS	NS

[1]All stumps were included in the analyses of the first four variables; only stumps having one or more sprouts were considered in the analysis of height of the tallest sprout.

When the data on high-cut and low-cut stumps were analyzed separately, there were no apparent differences in characteristics between stumps that sprouted and those that did not. Regression analyses indicated that the number of sprouts per stump was not significantly related to the height variation among the high-cut stumps (13 to 50 inches) or the low-cut stumps (3 to 11 inches), to diameter at 16 inches, or to cut-surface diameter. It should be stressed, however, that all stumps originated from a mature, even-aged stand. If these relationships were tested for stumps over a range of sites and age classes, some significant trends might be found.

Figure 2.--A typical high-cut stump had four sprouts which averaged more than 2 feet high (A), whereas a typical low-cut stump did not sprout (B).

The pronounced difference in sprouting between high- and low-cut stumps, which was also found in the previous study of swamp tupelo seedlings in a nursery bed,[4] could involve several factors. First, early sprout growth occurs primarily at the expense of food reserves in parent stumps and roots, and more food reserves (i.e., more stem tissue) should be available for sprout production on high-cut stumps than on low-cut stumps. Second, the previous study established that sprouts on swamp tupelo arise from suppressed buds, and high-cut stumps contain more lateral surface area on which suppressed buds may be present and develop after cutting. If food reserves or lateral surface area were controlling factors in themselves, however, a more or less continuous relationship between stump height and sprout production would be expected. Such a trend was not apparent from regression analysis. Apparently, food reserves were not limiting factors during any year of the study.

Observations that most sprouts arise near the tops of stumps suggested a third possibility--namely, that the number of suppressed buds per unit of lateral surface area is greater at higher levels above the ground and lower in the basal region of any given stump. This hypothesis was checked by peeling the bark from three freshly cut stumps in the study area. More than twice as many suppressed buds were present per square foot of surface area at 6 to 11 inches above ground (11 buds) than in the region 0 to 6 inches above ground (5 buds). Physiological and environmental factors possibly account for this difference in the presence of buds. In the previous study, it was pointed out that swamp tupelo seedlings produce hypocotyls 1 to 3 inches tall and that no suppressed buds are produced in the hypocotyl region. The decreased sprouting of the low-cut seedlings in the nursery probably resulted because they were cut $\frac{1}{2}$ inch above ground, in the region below the hypocotyl. In the present study of stumps from mature trees, however, all low-cut stumps were at least 3 inches tall and, consequently, should have contained suppressed buds. It is possible that sprouting was reduced on these low-cut stumps because the suppressed buds near the base of the stumps were killed by the prolonged flooding to which all trees in the stand had been subjected.

MANAGEMENT IMPLICATIONS

Forest owners can either deter sprouting by requiring loggers to cut stumps low or favor sprouting by allowing stumps to be cut high. In the first alternative natural or planted seedlings would be favored, and in the second the stump sprouts would likely be favored. The choice made depends, at least in part, on the type of regeneration that is preferred by the owner, the relative costs, and growth rates in later years. However, observations on a related species, water tupelo (Nyssa aquatica L.), indicate that height and diameter growth are as good, or better, on sprouts as on trees of seed origin.[5] A 30-year-old stand of

[4] Ibid.

[5] Hook, Donal D., LeGrande, W. P., and Langdon, O. Gordon. Stump sprouts on water tupelo. South. Lumberman 215(2680): 111-112. 1967.

water tupelo originating primarily from stump sprouts had sprouts averaging 76 feet tall and 13 inches in diameter. Comparable trees of seed origin were 74 feet tall and about the same in diameter. If long-term relative growth of swamp tupelo sprouts is found to equal or approach these rates, the alternative of favoring stump sprouts by cutting stumps high appears to be quite attractive, especially when considered in combination with seedling regeneration.

DeBell, Dean S.
1971. Stump Sprouting After Harvest Cutting in Swamp Tupelo. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SE-83, 6 pp.

In a mature stand of swamp tupelo, cutting stumps high (average 25 inches) resulted in greater sprout production one growing season later than did cutting stumps low (average 6 inches). On high-cut stumps, more stumps sprouted and sprouts were more numerous and had greater aggregate lengths. Differences in sprout production associated with stump height were primarily due to decreased numbers of suppressed buds in the lower regions of swamp tupelo stumps. Residual stand stocking and year of harvest had no effect on sprout production. Differences in sprouting among high-cut or low-cut stumps could not be related to diameter at 16 inches above ground, diameter of the cut surface, or height of individual stumps. No root sprouts were produced.

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Fomes annosus: A Bibliography with Subject Index--1960-1970

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Fomes annosus: A Bibliography with Subject Index--1960-1970

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INTRODUCTION

In 1960 Koenigs (262) published a bibliography and subject index on *Fomes annosus* (Fr.) Karst. More than 400 titles were listed, covering literature up to that date. In the past 10 years, interest in *F. annosus* has greatly increased and nearly 600 more papers have been published. Because damage by *F. annosus* is related directly to the intensity of forest management, the fungus is expected to command continued interest since an ever greater percentage of the world's wood supply will come from intensively managed, artificially established forests. This bibliography was prepared to aid those wishing to use the recent literature.

The basic sources for most of the citations were four major abstracting journals: Forestry Abstracts (FA), Biological Abstracts (BA), Bibliography of Agriculture (BOA), and Review of Applied Mycology (RAM, now Review of Plant Pathology). The source for each title is given in parentheses following the citation. The numbers following the source abbreviation are the volume and page number of the abstracting journal, not the abstract number. We attempted to obtain copies of all publications listed and to index the contents from the originals. Citations for which originals could not be obtained or for which translations or English summaries were not available were indexed from the abstracts and are identified with asterisks. All citations are in the bibliographic style of the U. S. Department of Agriculture.

Abstracting journals were searched through December of 1969. A number of papers are included in the bibliography that had not yet appeared in these sources but had been published in available journals or had been received directly from the authors.

The method of subject indexing is essentially that used in the first bibliography. Notations following citations refer to categories in the subject index. The subject index is cross-referenced by citation number. The only changes from Koenigs' subject index are the addition or deletion of certain categories to reflect changes in the types of papers published.

Undoubtedly some papers on *F. annosus* were missed; papers in obscure journals, annual reports of research organizations, and similar publications are often not included by the abstracting journals. We did not list some papers that merely mentioned *F. annosus* but did not include

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new research or observations. Likewise, partial references taken from publications or other sources which could not be verified are not listed. We tried to index each citation completely; however, for general papers and those pertaining to many aspects of the disease, this was not always practical.

The authors acknowledge the assistance of Dr. Tauno Kallio, University of Helsinki, Finland, and Jim Pratt, Forestry Commission Research Station, Farnham, England, for comparing our bibliography with their files and pointing out references unknown to us.

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7. Russia: 8, 16, 17, 55, 67, 131, 160, 181, 182, 186, 231, 251, 258, 259, 260, 267, 298, 302, 305, 324, 340, 343, 355, 365, 370, 371, 375, 377, 378, 380, 381, 383, 384, 387, 388, 390, 413, 430, 494, 495, 501, 507, 513, 514, 515, 540, 571, 584.

8. Other Countries of the World: 6, 7, 66, 153, 186, 254, 309, 403, 451, 461, 493, 508, 550, 583

C. The Fungus as Studied in the Laboratory (includes media, soil, wood, and some host-related factors)

1. Cultural characteristics

a. Colony morphology: 32, 55, 394, 400.

b. Microscopic anatomy: 55, 83, 84, 85, 86, 173, 175, 176, 263, 315, 394, 490.

c. Cytology and ultrastructure (see C6c for cytogenetics): 18, 490, 522.

2. Chemical Factors (includes effect of the factor on *Fomes annosus* and of *Fomes annosus* on the factor)
   a. Carbon-nutrition and metabolism
      (1) Carbohydrates: 25, 134, 178, 193, 230, 233, 234, 282, 290, 316, 331, 337, 338, 339, 374, 377, 395, 396, 397, 399, 431, 510, 516, 543, 552, 584.

      (2) Lipids (other than resins and phenols): 172, 233, 290, 339, 374, 377.

      (3) Resins: 70, 71, 290, 430, 496.

      (4) Phenols: 25, 26, 130, 137, 178, 193, 234, 290, 317, 319, 338, 374, 493, 496.

      (5) Other: 304, 460, 536.

   b. Nitrogen-nutrition and metabolism (other than enzymes): 28, 55, 134, 175, 178, 180, 232, 233, 338, 374, 455, 460, 552.

   c. Enzymes: 14, 26, 78, 130, 132, 135, 178, 230, 234, 243, 317, 318, 319, 331, 374, 377, 394, 396, 397, 399, 431, 448, 493, 543, 584.

   d. Metallic elements—nutrition and metabolism
      (1) Macroelements: 175, 374, 455, 538, 557.

      (2) Microelements: 23, 79, 175, 178, 538.

   e. Nonmetallic elements (other than carbon and nitrogen)—nutrition and metabolism: 88, 374, 431, 455.

   f. pH [see also E5a(2)]: 55, 67, 82, 150, 173, 178, 180, 232, 234, 291, 305, 372, 377, 395, 399, 419, 552, 584.

   g. Aeration and composition of gases: 78, 135, 173, 174, 234, 386.

   h. Water (includes moisture content, relative humidity): 377, 484, 485, 486, 530, 567, 584.

   i. Fungal metabolites: 24, 25, 55, 80, 159, 175, 176, 178, 203, 230, 232, 257, 331, 374, 382, 395, 396, 397, 473, 516, 532, 543.

   j. Toxicants
      (1) Natural host: 25, 178, 226, 239, 289, 304, 428, 496, 514, 535, 539, 557.

      (2) Fungicides: 179, 180, 219, 235, 236, 263, 264, 509, 535, 536.

      (3) Antibiotics: 133, 159, 173, 175, 176, 178, 203, 224, 375, 523, 538, 553, 560.

(4) Other: 26, 87, 178, 252, 253, 386.

k. Vitamins and growth factors: 28, 87, 175, 178, 233, 377, 382, 431, 551, 552.

l. Other: 100, 223, 226, 233, 252, 374, 377, 496, 514.

3. Physical Factors
   a. Temperature: 81, 161, 163, 172, 178, 195, 226, 257, 305, 318, 379, 399, 419, 480, 484, 485, 486, 491, 504, 552, 567.

   b. Radiation: 305, 369, 376, 419, 484, 485, 486, 530, 553, 554.

   c. Other: 389, 584.

4. Life Cycle
   a. Growth: 70, 71, 81, 82, 87, 163, 172, 174, 175, 177, 180, 224, 226, 264, 290, 305, 372, 375, 376, 379, 382, 394, 480, 551.

   b. Sporulation: 51, 173, 252, 264, 308, 484, 485.

   c. Germination: 100, 180, 226, 264, 305, 338, 372, 379.

   d. Other: 175, 178, 373.

5. Effect of Fungus on Wood
   a. Effect on physical characteristics: 11, 45, 74, 79, 143, 256, 257, 282, 377, 428, 429, 455, 589.

   b. Effect on chemical characteristics: 45, 78, 239, 282, 377, 397, 427, 455, 496, 510, 516, 526, 583.

   c. Effect on anatomical characteristics: 67, 526, 589.

   d. Effect on other characteristics: 79, 526, 589.

6. Variation and Genetics
   a. Physiological variation (include wood-rotting capacity, virulence): 11, 24, 25, 55, 80, 81, 150, 173, 176, 177, 224, 228, 428, 429, 493, 509.

   b. Other variation (sporulation, cell type, colony morphology): 32, 290.

   c. Cytogenetics: 15, 58, 171, 563, 564.

7. Physiology of Parasitism: 377, 431, 530.

8. Physiology of Resistance (see E5f): 163, 496.

9. Miscellaneous: 162, 177.

D. Fungus in Nature
1. Sporophore Description: 83, 84, 158, 188, 292, 293, 336, 344, 406, 447, 451, 461.

2. Location of Sporophores: 2, 49, 55, 158, 188, 202, 237, 292, 293, 294, 309, 336, 344, 406, 410, 486, 504, 507, 520, 524.

3. Attack on Forest Products: 153, 273, 410, 464, 504, 513, 515, 519, 524.

4. Role as a Forest Saprophyte: 2, 276, 282, 334, 378, 406, 438, 456.

5. Spore Production and Dispersal (see also E2a)
a. Conidia: 32, 52, 221, 246, 260, 327, 353.

b. Basidiospores or spores in general: 49, 121, 124, 188, 240, 245, 246, 247, 248, 314, 327, 332, 333, 404, 405, 406, 456, 457, 463, 464, 474, 484, 485, 486, 500, 503, 540, 548, 568, 574, 577.

6. Survival in Wood and Soil: 34, 95, 128, 158, 194, 275, 280, 332, 333.

7. Taxonomy: 83, 84, 85, 86, 315, 390, 451, 493.

8. Detection: 19, 21, 76, 96, 99, 184, 195, 205, 274, 275, 284, 292, 333, 362, 369, 427, 428, 449, 457, 467, 508, 568, 569, 581, 589, 592.

E. Disease in Trees and in Stands
1. Points of Entry into Host
a. Roots, general: 74, 97, 197, 265, 313, 444, 479, 488.

b. Root grafts or root contacts: 49, 158, 165, 198, 260, 410, 445, 482, 528.

c. Dead roots: No citations

d. Live roots——injured: 98, 185, 197, 220, 323, 392, 393, 415, 499.

e. Live roots——uninjured: 150, 197, 528.

f. Stumps
(1) Duration of stump susceptibility: 73, 333, 478, 574, 577.

(2) Temperature effect on susceptibility: 112, 116, 117, 121, 155, 333, 456, 481, 482, 519, 574, 577.

(3) Host species variation in susceptibility: 69, 72, 581.

(4) Rate of growth in stump: 53, 93, 285, 286, 334, 469, 504, 529.

(5) General: 21, 29, 31, 48, 49, 56, 95, 109, 116, 122, 158, 313, 332, 334, 358, 410, 442, 444, 447, 454, 456, 482, 500, 548, 575, 581, 593.

g. Trunk wounds: 138, 220, 322, 323, 392, 393, 415, 488, 498, 499, 565.

h. Fence posts: 261, 579.

i. Soil: 150, 313, 378, 528, 593.

2. Means of Spread——also see points of entry, e.g., root contacts
   a. Spores: 21, 93, 95, 121, 158, 188, 196, 214, 221, 240, 244, 245, 247, 279, 327, 357, 358, 410, 447, 449, 457, 520, 586.

   b. Mycelial strands: 2, 142, 363, 515.

3. Symptoms
   a. Gross tree symptoms: 25, 49, 255, 297, 356, 358, 370, 401, 447, 494, 504, 508, 566.

   b. Description of rot: 158, 163, 194, 205, 293, 343, 370, 387, 504, 521, 524, 528.

   c. Degree of infection before symptoms appear: 305, 336, 504, 566.

   d. Symptoms in stand: 358, 442, 447, 504, 521.

4. Seriousness of *Fomes annosus* Attack
   a. Extent of rot in tree: 49, 65, 90, 216, 220, 255, 265, 302, 383, 384, 393, 402, 403, 447, 455, 495, 498, 499, 504, 566, 570, 586, 588, 590, 592, 593.

   b. Intensity of infection in stand: 27, 31, 49, 62, 96, 105, 115, 117, 144, 148, 189, 190, 192, 198, 204, 216, 223, 237, 241, 244, 245, 249, 251, 270, 301, 312, 321, 323, 335, 336, 340, 350, 351, 357, 358, 365, 380, 381, 384, 387, 401, 402, 411, 437, 447, 482, 487, 504, 506, 507, 541, 545, 546, 591, 592, 593.

   c. Economic loss: 6, 46, 66, 113, 115, 148, 166, 189, 293, 313, 321, 335, 359, 366, 447, 452, 468, 498, 499, 546.

   d. Rate of spread: 2, 38, 139, 249, 271, 336, 351, 380, 381, 410, 454, 466, 504.

   e. General surveys: 144, 156, 165, 181, 218, 251, 267, 269, 297, 329, 487, 488, 542, 562.

5. Factors Affecting *Fomes annosus* Attack
   a. Soil
      (1) Chemical nature of soil: 42, 43, 79, 88, 145, 146, 149, 151, 158, 165, 222, 272, 288, 289, 301, 313, 328, 336, 346, 347, 349, 364, 411, 454, 455, 466, 488, 492, 507, 545, 546, 547, 593.

      (2) Physical and structural nature of soil: 91, 145, 146, 151, 182, 217, 219, 313, 323, 328, 336, 346, 352, 355, 392, 402, 507.

(3) Drainage or moisture relations of soil: 64, 158, 182, 217, 242, 249, 254, 288, 301, 305, 328, 336, 352, 381, 387, 392, 401, 507, 530, 531, 557.

(4) Soil, general: 98, 107, 191, 216, 305, 322, 393, 437, 450, 475, 488, 524, 541, 545, 582.

b. Effect of site, site quality, host range, and geographical location: 9, 17, 35, 64, 66, 145, 146, 158, 191, 192, 217, 231, 242, 288, 289, 305, 340, 349, 380, 387, 388, 437, 450, 593.

c. Effect of climate: 17, 188, 190, 269, 334, 347, 352, 456, 457, 466, 475, 503, 504.

d. Effect of aspect, slope, or elevation: 64, 66, 301, 305, 328, 437, 524, 581.

e. Variation in host (interspecific) resistance: 43, 62, 69, 74, 94, 144, 151, 209, 226, 228, 242, 281, 283, 287, 313, 342, 368, 383, 402, 423, 425, 428, 429, 476, 492, 498, 499, 500, 545, 546, 574, 582.

f. Effect of individual tree factors
(1) Age: 64, 66, 98, 145, 151, 158, 215, 251, 301, 305, 340, 381, 383, 384, 425, 466, 488, 492, 501, 540, 593.

(2) Vigor: 149, 151, 222, 265, 305, 334, 337, 338, 339, 384, 496, 508, 547, 593.

(3) Resin production: 34, 71, 149, 151, 152, 289, 299, 300, 305, 337, 338, 377, 428, 466, 496, 547.

(4) Genetic factors: 41, 94, 151, 305.

(5) Other: 158, 235, 236, 239, 338, 339, 369, 428, 492, 496, 584, 590.

g. Pathogenicity of fungus
(1) Strains of *Fomes annosus*: 74, 283, 338.

(2) *Fomes annosus* as a pathogen: 151, 225.

h. Effect of thinning: 31, 35, 40, 48, 114, 117, 125, 126, 139, 199, 219, 237, 265, 306, 321, 329, 332, 349, 351, 408, 410, 434, 437, 442, 487, 499, 504, 521, 524, 528, 542, 545, 546, 555, 562, 578, 580, 581, 582.

i. Effect of former land use
(1) Agricultural: 42, 63, 89, 114, 144, 145, 270, 272, 301, 349, 355, 454, 542, 545, 546, 582.

(2) Non-agricultural: 63, 107, 145, 158, 165, 198, 222, 272, 542, 545, 546, 582.

j. Effect of rotation (first vs. succeeding): 118, 158, 165, 166, 198, 215, 216, 272, 287, 423, 454, 466, 482, 504, 546, 582.

k. Effect of fire: 144, 145, 244, 245.

l. Method of establishing stand
(1) Planting: 8, 48, 198, 287, 307, 351, 434, 437, 542.

(2) Direct seeding and natural regeneration: 8, 48, 198, 287, 351, 434, 437, 542.

F. Inoculation
1. Stumps
a. Roots: 97, 151, 209, 279, 333, 403, 441, 465, 467.

b. Surface: 53, 69, 72, 73, 110, 111, 117, 121, 195, 196, 285, 286, 333, 357, 465, 467, 478, 481, 529, 530.

2. Living Trees
a. Roots: 49, 149, 197, 337, 338, 339, 403, 504, 530, 531, 547, 483, 583.

b. Trunk wounds: 149, 370, 383.

3. Seedlings: 50, 94, 95, 225, 227, 228, 266, 277, 281, 283, 316, 531.

G. *Fomes annosus* and Other Organisms
1. Occurrence with Other Root Rots: 52, 165, 181, 246, 249, 265, 312, 333, 341, 499, 572, 593.

2. Occurrence with Other Fungi and Bacteria: 13, 21, 42, 52, 92, 96, 97, 99, 106, 180, 225, 252, 276, 278, 333, 334, 345, 410, 458, 469, 472, 572, 591.

3. *Fomes annosus* and Fungus Competition and Antagonism
a. In soil: 89, 101, 102, 103, 142, 149, 150, 168, 225, 252, 296, 325, 326, 333, 345, 346, 347, 363, 378, 391, 446, 541, 544, 547.

b. On cultural media: 25, 87, 88, 133, 149, 150, 161, 163, 178, 224, 228, 229, 257, 295, 346, 391, 419, 446, 458, 483, 544.

c. On or in stumps: 21, 52, 53, 54, 93, 121, 150, 168, 169, 179, 206, 211, 219, 244, 276, 285, 326, 332, 333, 334, 346, 385, 441, 463, 465, 466, 467, 468, 469, 472, 478, 529, 533, 555.

4. *Fomes annosus* and Insects: 68, 74, 221, 292, 330, 331, 334, 400, 504.

H. Control
1. Chemical Methods (includes creosoting, painting): 19, 37, 39, 48, 59, 107, 109, 110, 111, 112, 116, 120, 121, 123, 127, 129, 154, 166, 168, 170, 179, 180, 183, 211, 219, 235, 236, 244, 258, 305, 310, 313, 320, 332, 333, 350, 353, 356, 357, 358, 370, 383, 388, 409, 410, 420, 421, 423, 424, 426, 439, 441, 463, 464, 465, 467, 468, 471, 500, 504, 511, 555, 556, 575, 578, 580, 581.

2. Physical Methods (stump extraction, soil trenching, etc.): 107, 166, 170, 251, 258, 298, 324, 383, 416, 420, 421, 423, 424, 469, 471, 533, 579, 582.

3. Biological Methods: 20, 54, 120, 121, 166, 168, 170, 180, 187, 225, 258, 305, 391, 420, 422, 423, 424, 438, 458, 459, 464, 465, 467, 468, 469, 471, 472, 534.

4. Silvicultural
   a. Planting on correct site or in natural range: 305, 352.

   b. Planting trees in mixed stands: 8, 17, 89, 165, 303, 305, 313, 324, 355, 411, 513, 514, 540.

   c. Thinning: 112, 163, 260, 305, 320, 326, 330, 352, 356, 357, 371, 481, 520, 574, 577, 580.

   d. Delayed planting: 118, 471, 477.

   e. Other: 17, 107, 120, 144, 298, 313, 324, 370, 388, 498, 499, 514.

5. Other: 119, 301, 347, 371, 392, 579.

6. General: 16, 181, 255, 297, 387, 501.

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A bibliography and subject index of Fomes annosus literature is presented to facilitate access to the recent research findings on this important root-infecting fungus. Nearly 600 citations are listed.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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HE UNDERFLOOR PLENUM:

N ALTERNATIVE TO CONCRETE-SLAB AND CRAWL-SPACE CONSTRUCTION

y H E. Dickerhoof

SD Forest Service Research Paper SE-85 • September 1971

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The Underfloor Plenum: An Alternative to Concrete-Slab and Crawl-Space Construction

by

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How can wood-floor construction in single-family, one-story homes be improved for use in the South and Southwest? To answer this question, the Forest Service conducted a comprehensive research program which concentrated on the evaluation of wood-floor construction with an underfloor plenum (fig. 1) as an alternative to construction with concrete slabs and wood crawl-spaces. The research evaluated (A) the performance of a wood floor with a shallow underfloor plenum for both summer cooling and winter heating, (B) cost comparisons with construction incorporating wood crawl-spaces and concrete slabs, (C) building code regulations, and (D) market preferences.

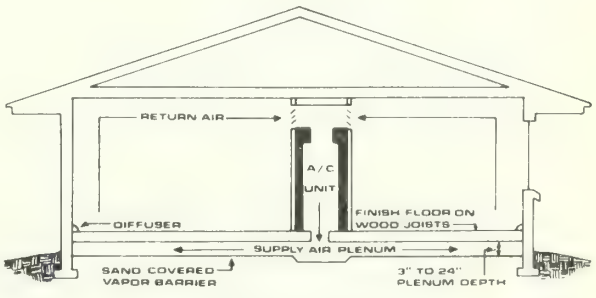


Figure 1.—Underfloor plenum with distribution of heated or cooled air throughout the house. Ductwork is not required for air delivery to the rooms.

Performance of the Underfloor Plenum

Previous Use and Performance Testing

Primitive forms of an underfloor plenum system for winter heating have been used in the Orient for centuries. The ancient Roman hypocaust is thought to be similar to modern plenums. Much of the heat obtained from this system was probably in the form of radiant heat from the floors in addition to that which may have been carried in primitive duct systems (*21*). However, the use of a true underfloor plenum has been limited in modern home construction and has had little publicity.

A modern plenum system must have a mechanical unit with a blower which builds up enough air pressure so that sufficient quantities of heated or cooled air can be delivered to room diffusers (*19*). Standard residential equipment can now be used to create the conditions necessary for a true ductless plenum.

The current interest in using the plenum system for home construction in the United States can be traced back to the early 1950's. On the basis of field tests conducted by The Warm Air and Heating Association, a home

building firm in Lincoln, Nebraska, began using an underfloor plenum for heating its new homes (*1*). The firm used a concrete-plank floor system of its own manufacture.

In the late 1950's, Dr. Gerald J. Stout at Pennsylvania State University began testing a special system of metal and wood floor-framing which could be used with an underfloor plenum (*23*). A limited number of houses were built with this floor system and an underfloor heating plenum in the early 1960's.

Also during the early 1960's, Mr. Andy Place of South Bend, Indiana, began building homes in which the crawl-space was used as a heating plenum (2, 16). Since that time,he has used this design with various systems of wood and metal floor-framing in approximately 700 homes.

During the same period, experimentation with underfloor plenum systems for heating homes was conducted at the U.S. Steel Research Center at Monroeville, Pennsylvania. Such systems were used in a number of experimental houses at the Monroeville research facility.

In December of 1963, Mr. John Talbott of Washington State University published the findings of his research on low-profile wood-floor systems (*24*). This research included the construction and instrumentation of a test house to study the performance of the plenum system for heating. In eastern Washington and in Idaho, Talbott later supervised the construction of numerous houses incorporating various systems of wood floor-foundations with underfloor plenums, some of which were built in cooperation with Potlatch Forests, Inc.

In 1964 in Charles Town, West Virginia, the Agricultural Research Service built a test house in order to test various systems of warm-air heating for low-cost homes (*21*). One contribution of this research was the development of an improved yet economical heating system which meets the restrictions of the National Fire Code. With this design, air at room temperature is circulated in the plenum and then throughout the house through a perimeter slot; a low-cost heating unit can be used because the warm air is circulated from the ceiling into the plenum.

Evaluation of an Underfloor Plenum for Heating and Cooling

Between February 1966 and September 1970, the Forest Service participated in a series of cooperative research agreements with the University of Florida to determine the feasibility of using a low-profile underfloor plenum for both heating *and* cooling homes in the Southern United States. Four reports on this research have been published (*8*, *11*, *18*, *19*).

In late 1966, the construction of a test house was begun in Gainesville, Florida, by the Southeastern Forest Experiment Station in cooperation with the Bureau of Research of the University of Florida's College of Architecture and Fine Arts. The construction and partial instrumentation were completed by early 1967 (*8*).

The 1,850-sq.-ft. test house has a conventional floor-joist framing system. The floor joists are approximately 6 inches above the washed sand ballast which covers the ground vapor barrier. This vapor barrier is polyethylene lapped 6 inches at the joints but not sealed. The vapor barrier was installed so that it continues up the side of the foundation walls and is cut off about 2 feet up the inside of the exterior stud walls. Polystyrene insulation board, ½ inch in thickness, was installed along the perimeter of the foundation wall.

The test program was conducted with the standard equipment normally used in a home with central air conditioning. For the first 2½ years, this equipment consisted of a gas-fired, counterflow furnace with evaporator coils below (Unit A). The only ductwork used with Unit A was a 5-ft. section for overhead air return in the central hall. In the summer of 1969, the furnace was replaced by an electric heat pump (Unit B) located at one end of the house. Unit B uses a completely free or open system for return air inside the house.

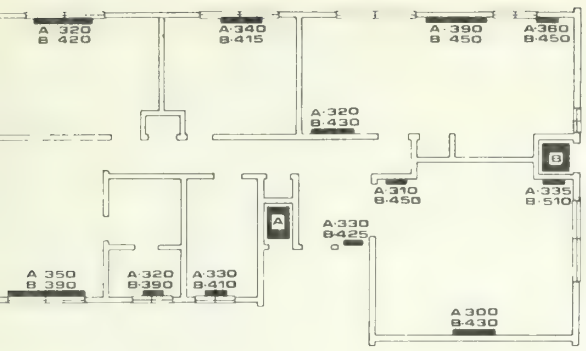
The test observations concentrated on air distribution, control of air temperatures in the rooms, floor temperatures, relative humidity, and moisture content of the wood floor and floor framing.

Air Distribution

During the operation of Units A and B, the air distribution throughout the house was relatively uniform. The velocities of air discharge at the diffusers were higher when Unit B was in operation, but this difference was attributed to the difference in fan outputs between the two units (fig. 2). The fan output for Unit A was approximately 1,200 cubic feet per minute, while that for Unit B was approximately 1,600 c.f.m.

Smoke tests showed that the air was well diffused throughout the rooms. Even in those rooms with high, open-beam ceilings, there was no evidence of air stagnation during either the cooling or heating periods.

In the plenum, the air tended to radiate evenly from the source with only slight fluctuations which were attributed to the geometry of the test structure. Even though discharge velocities and air diffusion were uniform throughout the house, the air velocity



gure 2.—Typical velocities of air discharge (in cubic feet per minute) from the underfloor plenum at individual diffusers during the operation of mechanical Units A and B. Note the relatively uniform discharge velocities.

the plenum decreased as the distance creased from each mechanical unit (figures 3 d 4). With both units, the air moved rpendicular to the joists in reaching several of e diffuser outlets, but this movement parently failed to influence air velocities in e plenum.

r Temperatures

Temperature readings were taken at heights of 30, and 60 inches in all rooms throughout the test house. During periods when cooling was required, a maximum differential of 4° F. was observed in the kitchen, which was designed to create adverse conditions for temperature control. Located in the southwest corner of the house, this room has a considerable area of glass, and the ceiling consists of exposed roof decking and rafters. In the other rooms, the average differential between the 6- and 60-inch heights was only about 2½° F.

Temperatures were even more uniform when heating was required. The average differential was less than 2° F. and the maximum observed was 3½° F. This small difference was largely attributed to heat which was transferred from the plenum directly through the floor, thus supplementing the heated air transferred through the diffusers.

The test observations indicated that good temperature control could be maintained in the house during periods when wide variations in outside temperatures required intermittent heating and cooling. This problem is common to all systems in many areas of the United States.

During periods when the outdoor temperature increased rapidly, continuous operation of the fan enabled the underfloor-plenum system to gain an advantage over systems with conven-

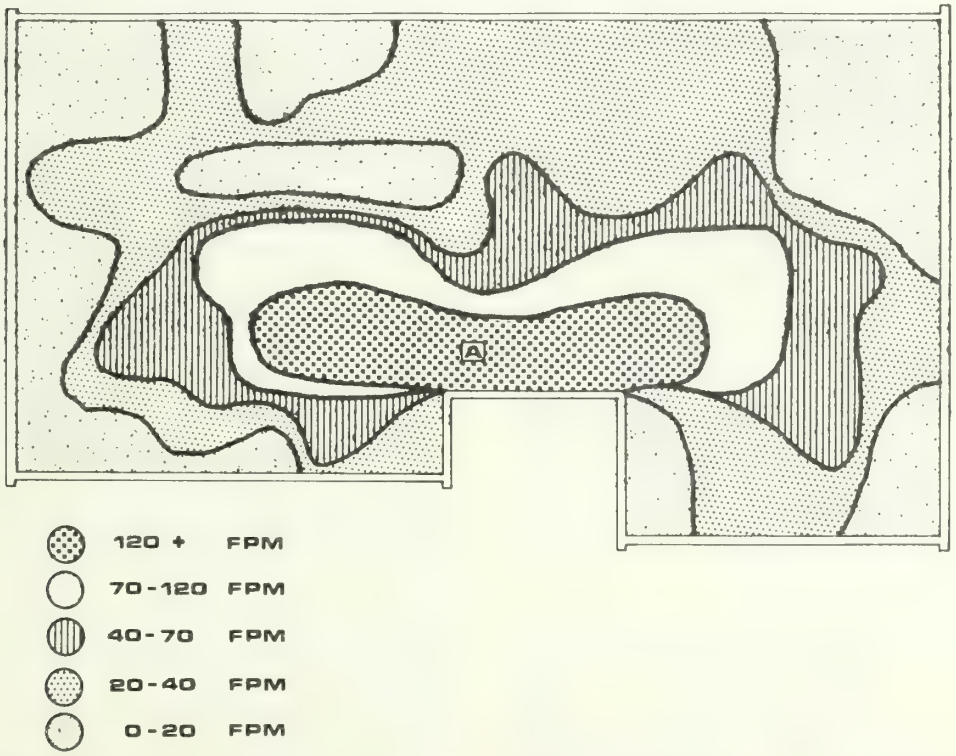


Figure 3.—Typical air velocity pattern (in feet per minute) in the plenum while mechanical Unit A was in operation.

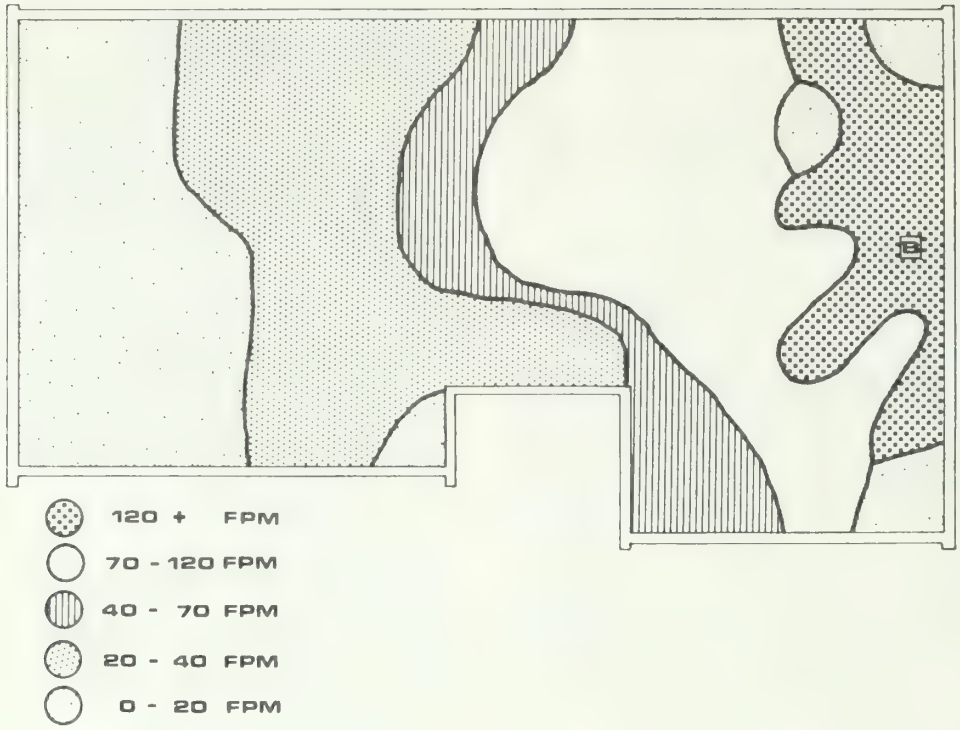


Figure 4.—Typical air velocity pattern (in feet per minute) in the plenum while mechanical Unit B was in operation.

tional ducts. Essentially, continuous operation of the fan takes maximum advantage of the storage of natural energy in the plenum and allows the stored heat to be supplied to the rooms at a decreasing rate as the outdoor temperature rises. Utilization of this stored heat results in a reduction in furnace operation with a consequent reduction in fuel consumption.

Floor Temperatures

During the winter the floors were comfortably warm. The highest temperature recorded on the floor surface was 84° F. near the mechanical unit. The lowest such temperature recorded was 73° F. at one corner of the house.

Temperatures at the floor surface were also moderate during the summer when the plenum was used for cooling. The minimum temperature recorded was 70° F. near the mechanical unit. The maximum temperature recorded was 73° F. in one corner of the house.

Relative Humidity

Although relative humidity is a definite factor in determining thermal comfort, most people have difficulty in identifying changes in relative humidity between 20 and 70 percent when temperature and air movement are stable and within reasonable limits. The use of humidity control devices in residential mechanical systems is still somewhat limited; consequently, the mechanical units used in these tests did not include specific controls for this factor. However, observations of relative humidities in the test house during the cooling cycle showed that no problems or unusual conditions were created by using the plenum for cooling (*19*). No humidity problems would be anticipated with the use of plenum construction as long as proper drainage is maintained and an adequate ground vapor barrier is installed at the time of construction.

Moisture Content of Wood Floors and Framing

An important aspect of the test program has been the continuous monitoring of the moisture content in the wood-floor system. Moisture content ranged from 7 to 25 percent in the wood members tested at the time of delivery to the site. During construction, approximately 60 moisture probes were installed in the floor joists, sills, subfloor, and finish flooring.

After the operation of Unit A began, moisture content of the wood members settled down to a desirable range between approximately 6 and 13 percent (fig. 5). This range is not conducive to the development of decay organisms. When Unit B began operation in 1969, no change in the pattern of moisture content was observed.

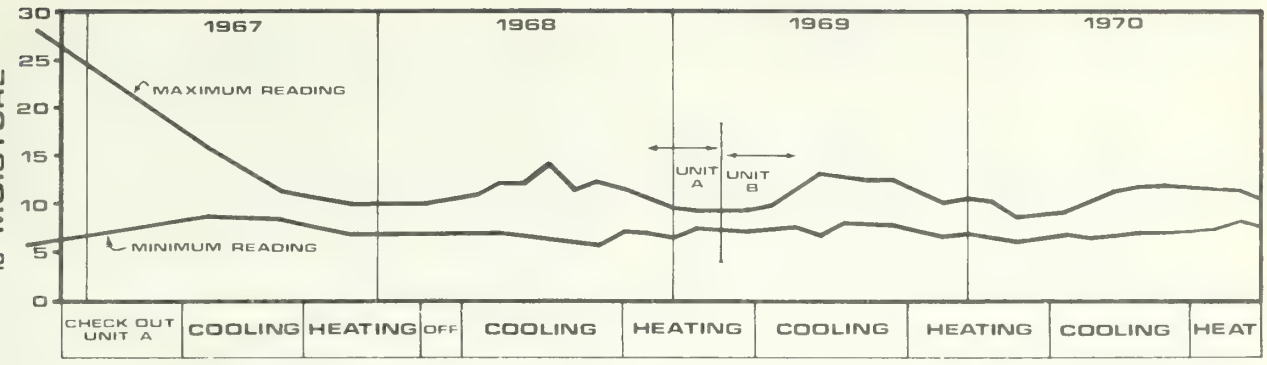


Figure 5.—Range in wood moisture content recorded at 17 stations in the floor system during the operation of the underfloor plenum from December 1966 to December 1970. (Each station had several moisture probes in adjacent wood members.)

In any construction utilizing wood, moisture ontent should be controlled at all times in rder to minimize possible shrinking or swelling. he test observations indicated that desirable nd stable levels of moisture content can be naintained in the wood members of a house ith an underfloor plenum.

Summary on Plenum Performance

At a test house in Gainesville, Florida, obser- ations of air flow, air temperatures, floor emperatures, relative humidity, and moisture ontent of wood members demonstrated that:

A. An underfloor-plenum system can be used for heating and cooling a typical one-story residence.

B. Heated or cooled air can be distributed effectively to all areas of the house.

C. Room temperatures can be controlled easily during both winter and summer as well as during the intermediate seasons.

D. Floor temperatures are especially comfortable during the winter.

E. Humidity problems do not occur in either the rooms or the underfloor plenum.

F. Moisture content of the wood flooring and floor framing can be expected to stabilize within a desirable range.

Estimated Costs of Crawl-Space, Concrete Slab, and Plenum

Cost estimates were made for the wood rawl-space, concrete slab, and underfloor lenum in 24 cities. Although these cost stimates took into account several construction ractices and geographic conditions, FHA inimum property standards were used as a uide to construction specifications.

Development of Models for Estimating Costs of Floor Construction

The estimating models used in the study were sed on a plan for a house with 1,680 sq. ft. of oor area, the approximate size of an average w house (*29*). From this basic floor plan, an timating model for each of the three types of oor systems was developed after consultation d advice from many contractors, subcon- actors, architects, and material suppliers from ast to coast. The designs of the models and ality of materials used in the estimates are tended to represent good construction. Standard waste factors for the materials were computed and applied to all estimates where applicable.

Cost data for all three models are based on foundation-wall construction with concrete blocks. Estimates for floor framing with the crawl-space and plenum assume the use of 2- by 8-inch wood joists, 16 inches on center, unless otherwise indicated.

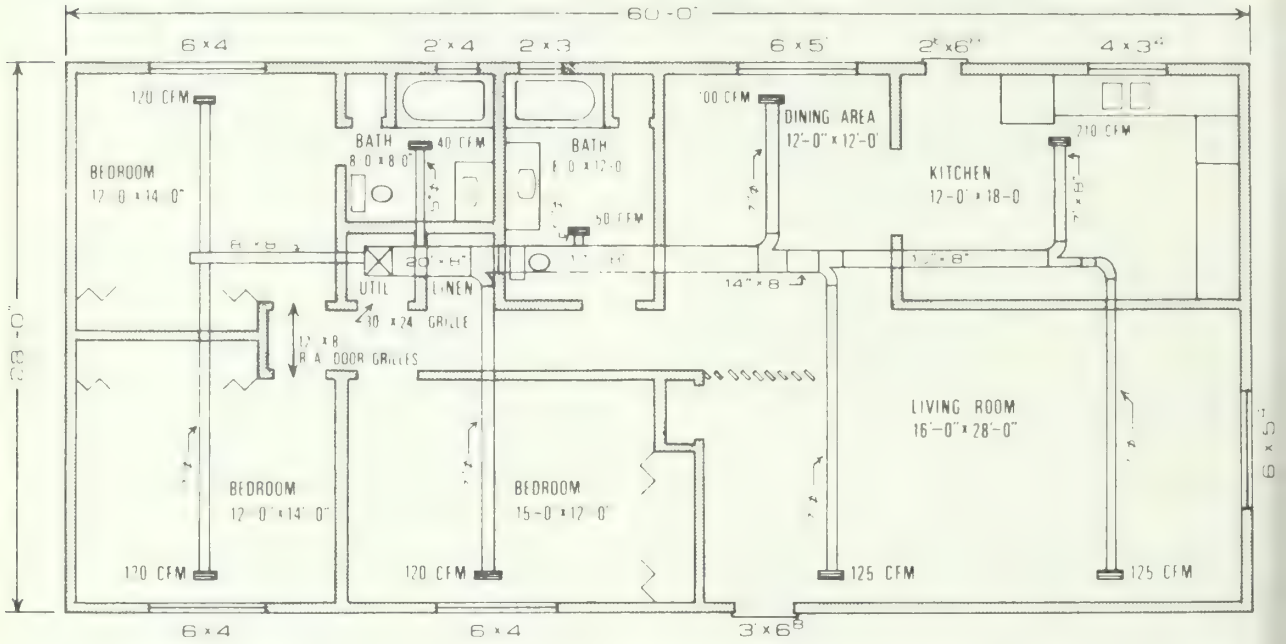
Wood beams and joists may be pressure-treated with preservatives if considered necessary, at a cost of approximately $40 per M bd. ft. This cost was included in the plenum floor-framing and the wood sleepers (i.e., screeds) for the oak-strip flooring over the concrete slab.

It was assumed that the soil would be chemically treated for termite protection prior to the construction of any of the three floor

systems. On the basis of information obtained from the National Pest Control Association, $75 was included for pretreatment of the soil.

For the two wood-floor systems, 5/8-inch plywood was used for the subfloor. Underlayment or Standard grades of plywood were used as appropriate under the various finish floors.

To estimate the cost of ductwork which would normally be used in a house with the floor plan of the 28- by 60-ft. estimating model, a heating and air-conditioning consultant was asked to design an appropriate ductwork system. The ductwork design used for estimating purposes is shown in figure 6. Cost estimates were obtained for each of the 24 cities surveyed (fig. 7).



FLOOR PLAN - AIR CONDITIONING DETAIL

NOTE DUCT WORK 24 & 26 GAUGE GALVANIZED STEEL INSULATE WITH 1 INCH FIBER GLASS DIFFUSERS EQUAL TO HART & COOLEY DOUBLE DEFLECTION

Figure 6.—Floor plan of model house and ductwork design used for cost estimates.

Figure 7.—Cities selected for cost estimates of concrete-slab, crawl-space, and underfloor-plenum construction. Cost estimates for ductwork are shown for each city.

Model for Underfloor Plenum

The design of the model used for estimating the cost of the underfloor plenum is illustrated in figure 8. In this design, which may be varied to meet local preferences and building codes, wood floor-framing that has been pressure treated with preservative is placed on the first course of 8- by 8- by 16-inch concrete blocks. The 2- by 8-inch floor joists are butted against a second course of 4- by 8- by 16-inch blocks laid on the perimeter of the first course. A ground vapor barrier of 6-mil polyethylene is covered with 2 inches of sand ballast. The vapor barrier extends up inside the wall framing to provide a good air seal. Perimeter wall insulation consisting of ½-inch sheets of rigid foam is cut to fit between the floor joists.

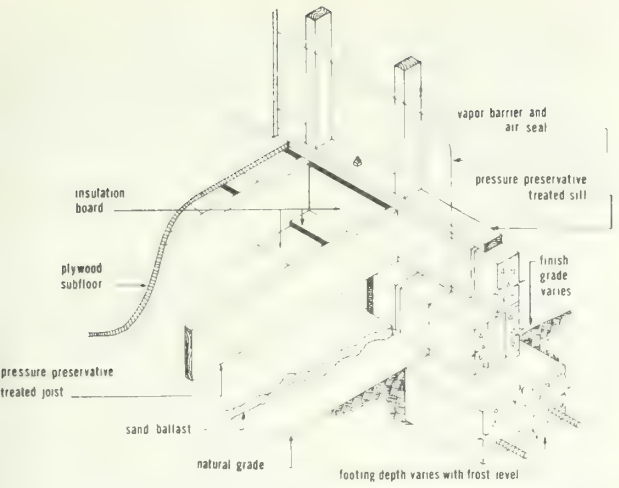


Figure 8.—Design of the model used for estimating the cost of the underfloor plenum.

This construction is similar to typical crawl-space construction. Thus, the major cost savings are realized from the elimination of expensive ductwork systems, although stub ducts could be extended outward from the central air-conditioning unit if required by the building code. (Depending on the house design used and the location of the mechanical unit, a few feet of ductwork may also be desirable to return the air to the unit.) Because a ductwork system is not required for heating or cooling, the home buyer who installs only a heating system at the time of purchase can add air conditioning later without the usual added expense of changing his ductwork system.

Model for Wood Crawl-Space

The design of the model used for the wood crawl-space is similar to that for the underfloor plenum except for the obvious differences in the height and configuration of the foundation wall (fig. 9). In the crawl-space design, the floor framing is a 2- by 8-inch joist system on 16-inch centers. The floor frame is on three courses of 8- by 8- by 16-inch concrete blocks. Neither perimeter wall insulation nor ground vapor barrier is included in this design, although these items may be included if warranted by local temperatures and soil and moisture conditions. Because the floor framing is more than 18 inches above the ground, pressure-treatment with preservatives would not normally be required.

Model for Concrete Slab

The design of the model used for the concrete slab includes a 4-inch trowel-finished slab with steel reinforcements and a vapor barrier installed over a 6-inch gravel base (fig. 10). The 16-inch-high foundation wall consists of two courses of concrete blocks: the first is composed of standard 8- by 8- by 16-inch blocks and the second of special J-blocks. (Standard blocks are sometimes used for the top course of a concrete slab, but J-blocks can usually be installed at the same cost.) The gravel base, which was estimated at $100, was included because builders and flooring subcontractors in some areas indicated that its omission often causes moisture problems that are difficult to correct after the slab floor is installed. Many areas in the Southwest have unstable soils which require careful installation and compaction of the base material as well as steel reinforcement of the slab itself.

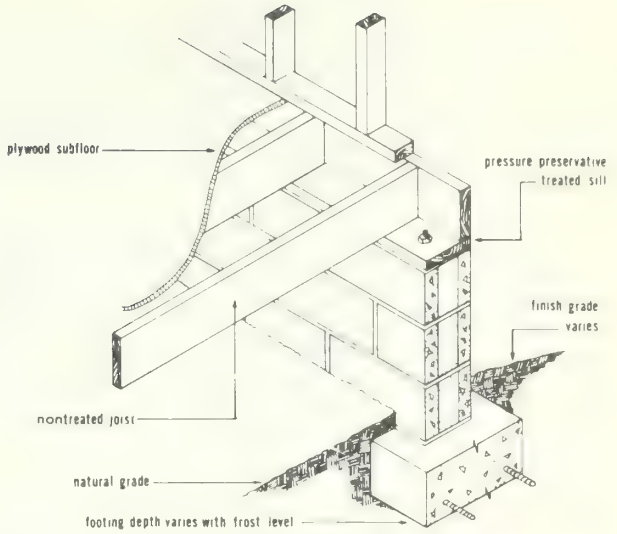


Figure 9.—Design of the model used for estimating the cost of the wood crawl-space.

Variations in the Three Models

Construction practices in some regions differ from those incorporated in the estimating

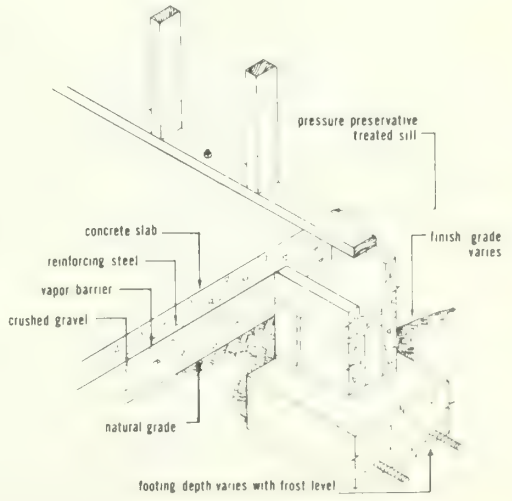


Figure 10.—Design of the model used for estimating the cost of the concrete slab.

models. Because poured foundation walls are common in certain areas of the South and Southwest, costs were computed on such walls 8 inches thick and 16 inches high for each of the three floor systems. It was found that poured concrete walls could save approximately $125 over concrete block walls.

Although the plenum and crawl-space models employed 2- by 8-inch joists with standard spans on 16-inch centers, 24-inch centers could probably be used if the joist and subfloor were nailed and glued on the job site. This method of construction has been developed by the American Plywood Association and has gained acceptance by many builders (*4*). It provides increased floor stiffness, limits squeakiness in floors, and has other advantages in addition to obvious cost savings.

Sources of Cost Data

The costs of basic labor and materials were compiled from a number of sources so that the estimates would reflect the most accurate, current prices for each geographic area. Subcontract rates were used in operations normally subcontracted or when separate labor and material costs were not available.

Although labor rates for cement finishers in Nashville, Mobile, Miami, and El Paso were obtained directly from contractors in those cities, most of the rates used for union labor were computed from information provided by local and regional offices of the U.S. Bureau of Labor Statistics. These labor rates were in effect in each city on February 16, 1970, and include insurance, pension, vacation, and other benefits paid by the employer. An additional 15 percent of the total labor cost was added for various employer costs, such as payroll taxes and employer's liability insurance.

Most unit costs for materials were based on data in the National Construction Estimator (*20*). These data were checked against data in other cost references. Subcontract rates and the prices of several materials were also confirmed by telephone interviews with builders and suppliers in selected cities. Prices of softwood lumber and plywood were adjusted by geographic location according to factors suggested in the Estimator.

The cost of ductwork was computed on a subcontract basis. Because of the importance of ductwork costs to this study, estimates were obtained from sheet-metal and air-conditioning contractors in each of the 24 cities. Their estimates were based on the floor plan and ductwork diagram shown in figure 7. Even though some regional differences in fabrication were expected, cost estimates among ductwork subcontractors were highly variable even within many cities. Three estimates for over $800 were judged to be unreasonably high and were not used. The ductwork estimates used in the study varied from a low of $300 in Memphis to $475 in New Orleans and Tampa, with a median of $425 (*10*).

Cost of Finish Floors

The costs of two floor finishes—oak strip and carpet—for the 1,300 square feet in the living room, dining room, and bedrooms of the model house were estimated for each type of floor system. With each of these finishes, the 220-sq.-ft. kitchen was estimated with a finish floor of medium-quality sheet vinyl and the 160-sq.-ft. bathroom areas were estimated with ceramic tile floors.

The estimates for oak-strip flooring were based on the use of select, plain-sawn oak, 25/32 by 2¼ inches. This type of finish floor was estimated to cost $0.92 per square foot including material, installation, sanding, and finishing.

Carpeting and pad were estimated to cost $8 per square yard installed (*3*). There are many variables to consider with carpet installations, but a number of firms indicated that this is a competitive price for medium-quality carpets.

Comparative Costs of Floor-System Construction

Figure 11 shows estimated costs for crawl-space, plenum, and slab-floor construction with oak-strip or carpet finish floors in each of the 24 cities.

Costs with Carpeting

In all 24 cities, the estimated cost for slab construction with carpet was less than that for the crawl-space with carpet. In 19 cities, the estimated cost for plenum construction with carpet was less than that for the slab with carpet; in the other 5 cities, the estimated cost for these two types was the same.

Costs with Oak-Strip Flooring

If oak-strip flooring rather than carpet is installed over a concrete slab, screeds that have been pressure-treated with preservatives are required by FHA minimum property standards. This treatment would make the cost of the crawl-space competitive with that of the concrete slab in most of the cities studied. With oak-strip flooring, the total cost of the plenum was less than that of the crawl-space and slab primarily because of the savings in ductwork

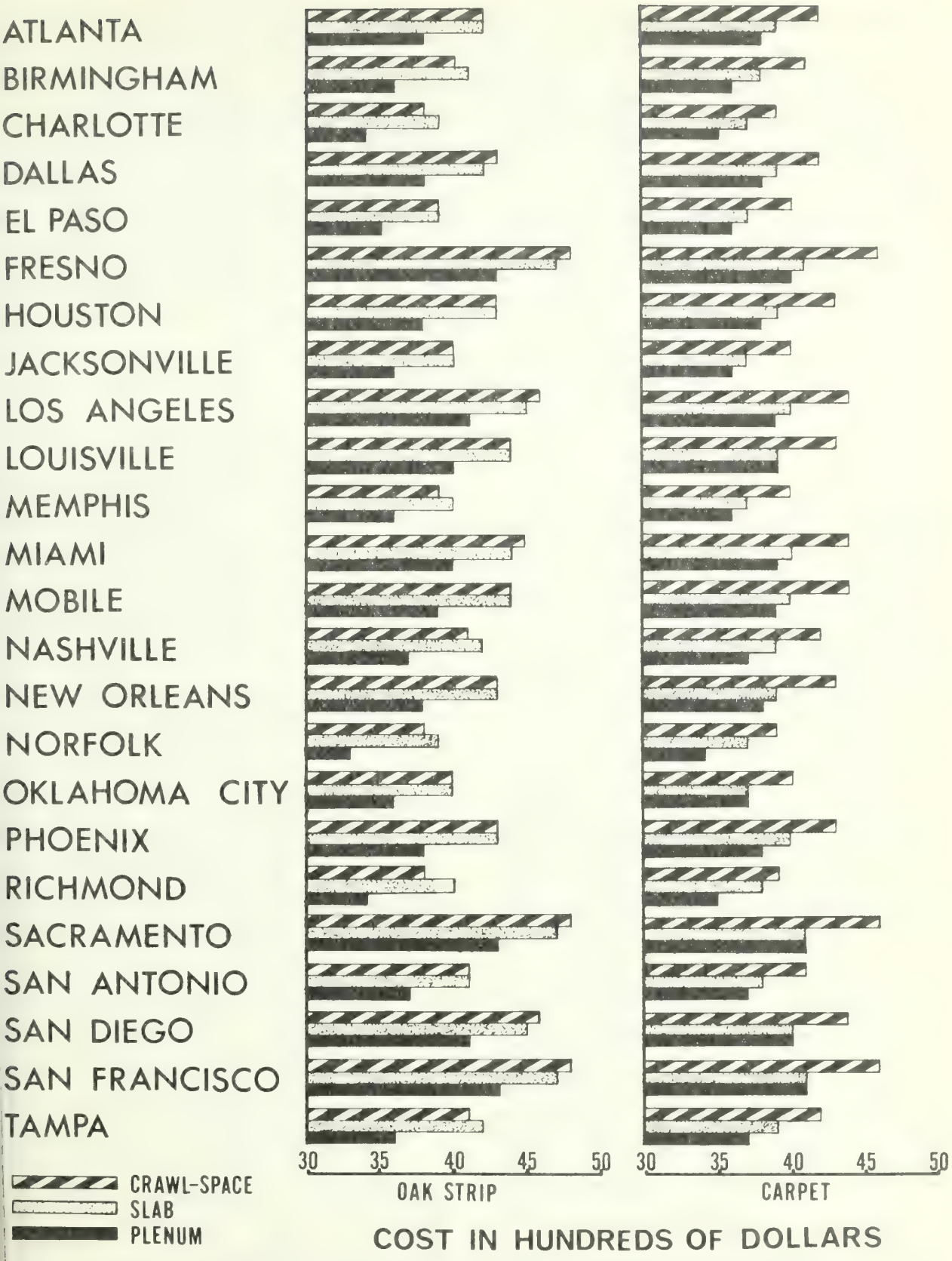


Figure 11.—Estimated costs of crawl-space, plenum, and concrete-slab construction with alternative finish floors for 24 selected cities, 1970. Ductwork costs are included in the estimates for the crawl-space and slab.

Summary on Costs of Crawl-Space, Slab, and Plenum

A. Wood-floor construction with an underfloor plenum and oak-strip flooring in the living area was estimated to cost less than either crawl-space or slab construction with the same flooring in all 24 cities.

B. Estimated costs of the slab and plenum were about the same with carpet in the living area, although plenum construction had a slight cost advantage in many cases.

C. In all cases, the plenum was estimated to be cheaper or at least no more costly than the slab with comparable finish floors.

D. Crawl-space construction with carpet was estimated to cost $100 to $600 more than comparative slab and plenum construction.

E. A major portion of the cost advantage gained by the plenum over the crawl-space can be attributed to the elimination of ductwork. Because ducts are not required for heating or cooling with plenums, the new home buyer who installs only the heating system at the time of purchase can easily install an air-conditioning system later.

Influence of Building Codes on Crawl-Space, Slab, and Plenum Construction

Introduction

The influences of building codes on crawl-space, concrete-slab, and plenum construction in new homes were evaluated in 27 cities and their surrounding counties. This evaluation pointed strongly to the problems that exist in interpreting building codes. Different officials often interpret the same or similar codes in different ways. The situation is often complicated when the model code is modified by local governments. Furthermore, city officials sometimes interpret a code differently than do the officials in the surrounding counties.

Variation in Termite Control Required

The requirements for the protection of wood floor-framing over crawl-space construction and wood flooring over slab construction varied from city to city (table 1). Several cities had no requirements for the protection of wood used in crawl-space or over concrete-slab construction (*6*).

A preliminary study in Florida revealed that termite shields were required with crawl-space construction in most major cities and their counties. Termite shields can be a good protective measure, but one study of over 300 randomly selected houses in Georgia showed that these shields are very rarely installed and maintained properly (*12*). None of the houses in the Georgia study had termite shields installed according to FHA minimum standards. Treatment of the soil prior to construction of crawl-space and slab homes has been a widely used, recommended, and effective method of controlling termites (*13*, *14*, *15*, *17*). But the recent concern about the possible contamination of the surrounding environment should be recognized. It is clear from previous research and use that soil treatment will protect the wood in homes from termite attack. However, most of the Florida jurisdictions studied did not require pretreatment of the soil for either crawl-space or slab construction (*5*, *7*). Both types of construction should have the benefit of some type of treatment to protect the wood. Soil treatment is desirable under the slab in order to prevent termite attack through any cracks that might develop in the slab itself. Treatment of all wood members in the house may eliminate the need to use soil pretreatments.

Dependence of Plenum Construction on Local Building Codes

Underfloor plenums in single-family homes would be permitted by building code officials in 15 of the 27 cities listed in table 2. Seven of the 27 counties listed in this table are not permitted by state law to adopt or enact building codes. If these seven counties are considered as permitting plenum construction, then such construction would be permitted in 20 of the 27 counties listed.

In several of the cities and counties where plenum construction is not now permitted, the problem of code acceptance would not be serious. Plenums could probably be used in several areas after further explanation is made to the local code official or slight modifications are made to meet local code provisions. However, the code official has the final word regardless of the guidelines outlined in the local code, unless an appeal is made to the local appeals board and this board overrules the code official. The ductless underfloor plenum should be permitted in all areas under the jurisdiction of the Southern Standard Building Code (SSBC) without special or unusual provisions. In those areas under the jurisdiction of the Uniform Building Code (UBC), it would probably be

Table 1.--Termite and decay protection required by 27 cities for wood floor-framing of houses with crawl-space and concrete-slab construction 1/

City	Crawl-space construction				Concrete-slab construction			
	Pressure-treated wood	Termite shields	Soil pretreatment	None required	Pressure-treated wood	Vapor barrier	Soil pretreatment	None required
Atlanta, Ga.	X				X			
Birmingham, Ala.	X2/	X	X2/		X2/	X	X2/	
Charlotte, N.C.	X		X					X
Dallas, Tex.				X	X			
El Paso, Tex.				X				X
Fresno, Calif.				X				X
Houston, Tex.				X				X
Jacksonville, Fla.	X3/	X			X	X		
Los Angeles, Calif.				X	X			
Louisville, Ky.				X				X
Martinez, Calif.	X4/				X5/	X6/		
Memphis, Tenn.	X7/	X7/	X7/		X2/	X	X2/	
Miami, Fla.	X				X			
Mobile, Ala.	X		X		X		X	
Nashville, Tenn.	X7/	X7/	X7/		X2/		X2/	
New Orleans, La.				X				X
Norfolk, Va.	X8/	X8/			X2/		X2/	
Oakland, Calif.	X9/				X10/			
Oklahoma City, Okla.		X					X	
Phoenix, Ariz.				X				X
Richmond, Va.	X							X
Sacramento, Calif.				X		X11/		
St. Petersburg, Fla.	X	X						X
San Antonio, Tex.	X3/							X
San Diego, Calif.	X3/				X12/			
San Francisco, Calif.	X				X	X		
Tampa, Fla.	X	X			X	X		

1/ Data based on Applefield (*6*).

2/ Soil pretreatment may be substituted for pressure-treatment.

3/ Wood floor joists require pressure-treatment if they are less than 18 inches above the ground.

4/ If in contact with ground.

5/ Sole plate and all wood within 6 inches from ground.

6/ Under all "living areas" of house.

7/ Pressure-treatment, termite shields, or soil pretreatment may be used.

8/ Either pressure-treatment or termite shields are required.

9/ All wood members within 18 inches of ground.

10/ Unless redwood sole plates are used.

11/ Vapor varrier must be gravel.

12/ Wood used in contact with concrete must be pressure-treated.

permitted if 6-foot stub ducts are extended outward from the furnace unit, noncombustible receptacles are placed under each floor opening, a 24-inch clearance is maintained between the bottom of the joists (the clearance may be reduced to 12 inches if beam or girder floor-framing is used instead of joist floor-framing), and the vapor barrier is covered by at least 2 inches of sand. The plenum is usually restricted by building codes to use in one-story, single-family houses, although it has been used successfully for heating two-story and split-level homes.

The most serious objections to the use of the underfloor plenum were raised by officials in Louisville who would not permit the use of the system because they thought it would be a fire hazard. The Basic Building Code is used in Louisville. Officials in Charlotte, Houston, Los Angeles, and Richmond indicated that the use of the underfloor plenum would not be permitted unless noncombustible materials were used or all materials in the plenum met a 2-hour fire-resistance requirement.

In Fresno, where plenum construction has been used more than in any other area studied, city officials expressed no misgivings about fire-hazard problems with such construction. This acceptance is noteworthy because Fresno has a long history of participation in programs on fire research and control. Fresno formerly permitted an underfloor plenum with a nonducted air supply and presently follows the requirements set forth by the Uniform Building Code.

The likelihood of a fire being started because of plenum construction seems very remote in view of the types of standard mechanical equipment which can be used and the low

Table 2.--Building codes in force in 27 cities and 27 counties in 1969 and decision of local code officials on whether they would permit construction of homes with underfloor plenums

City and county	Building code in force[1]	Underfloor plenum permitted	
		Yes	*No*
Atlanta, Ga.	L (NBC)	X	
DeKalb	NBC		X
Fulton	NBC	X	
Birmingham, Ala.	SSBC	X	
Jefferson[2]			
Charlotte, N.C.	L (SSBC)		X
Mecklenburg	L (SSBC)	X	
Dallas, Tex.	L (UBC)	X	
Dallas [2]			
El Paso, Tex.	SSBC		X
El Paso [2]			
Fresno, Calif.	UBC	X	
Fresno	UBC	X	
Houston, Tex.	L (UBC)		X
Harris [2]			
Jacksonville, Fla. [3]	NBC	X	
Duval [3]	NBC	X	
Los Angeles, Calif.	L (UBC)		X
Los Angeles	UBC		X
Louisville, Ky.	BBC		X
Jefferson	BBC	X	
Martinez, Calif.	UBC	X	
Contra Costa	UBC	X	
Memphis, Tenn.	L (BBC)	X	
Shelby	SSBC	X	
Miami, Fla.	L (SFBC)		X
Dade	L (SFBC)		X
Mobile, Ala.	SSBC	X	
Mobile [2]			
Nashville, Tenn. [3]	SSBC	X	
Davidson [3]	SSBC	X	
New Orleans, La. [3]	L (UBC)		X
Orleans [3]	L (UBC)		X
Norfolk, Va. [4]	SSBC	X	
Oakland, Calif.	UBC	X	
Alameda	UBC		X
Oklahoma City, Okla.	NBC	X	
Oklahoma [2]			
Phoenix, Ariz.	L (UBC)	X	
Maricopa [2]			
Richmond, Va.	BBC		X
Chesterfield	L (NBC)		X
Henrico	L (NBC)	X	
Sacramento, Calif.	UBC		X
Sacramento	UBC	X	
St. Petersburg, Fla.	SSBC	X	
Pinellas	SSBC	X	
San Antonio, Tex.	UBC		X
Bexar [2]			
San Diego, Calif.	UBC		X
San Diego	UBC	X	
San Francisco, Calif.[4]	L (UBC)	X	
Tampa, Fla.	SSBC	X	
Hillsboro	SSBC	X	

1/ L = Local Code. (Letters in parentheses indicate model code after which local code was patterned.) BBC = Basic Building Code. UBC = Uniform Building Code. NBC = National Building Code. SFBC = South Florida Building Code. SSBC = Southern Standard Building Code.

2/ The state does not permit counties to enact or adopt building codes.

3/ Construction in city, county, or parish is regulated by the same code and administrative personnel.

4/ Independent city.

temperatures to be expected in the plenum during the winter heating season. Furnace units which complied with standard safety requirements were used in the test house at the University of Florida. The air temperatures in the plenum were well below those normally found in most attic spaces during the summer. For example, during the heating cycle the air temperature at Unit A was measured at 110° F. and dropped to 79° F. at the more distant diffusers (*18*). Thus, if standard approved equipment is properly installed, the risk of a fire occurring with this system should be no greater than that with any other system.

Summary of Code Influences on Crawl-Space, Slab, and Plenum Construction

After evaluating the building codes and the responses of building code officials to several questions relating to floor-foundation construction in 27 cities and their surrounding counties, the following conclusions were reached:

A. A wide variety of code requirements and interpretations was found even among communities with similar codes. Furthermore, local governments often modify the adopted model code.

B. Requirements on termite and decay control varied considerably among communities. Termite shields are permitted or required for crawl-space construction in several areas, although they have been found to be ineffective because of improper installation and maintenance. More effective control measures are available, such as soil and wood treatments with chemicals.

C. Plenum construction would be permitted by building code officials in 15 of the 27 cities and 20 of the 27 counties evaluated. (Of the 20 counties considered as permitting plenum construction, seven are not permitted to enforce building codes.)

D. In several jurisdictions where building code officials now prohibit plenum construction, it is likely that permission to use the system would be granted if certain provisions were met regarding specific details of construction and if the officials were better informed about this system.

Market Preferences in Floor Construction

Introduction

The evaluation of market preferences for wood crawl-space, concrete-slab, or underfloor-plenum construction in new homes was begun in late 1967. All of the market areas selected have fairly warm temperate winters, and many have long, hot summers. Also, many of the areas have relatively level terrain where slab or crawl-space construction is commonly used. In several of the cities, concrete-slab construction is used in the majority of new homes. Thus, a preference for underfloor-plenum construction in these areas would be more meaningful than in areas where wood-floor construction is more common.

Pilot studies consisting of mail questionnaires to architects, builders, and new home buyers were conducted in nine areas in Florida—the largest market for single-family homes in the Southeast (27). These studies indicated that, although slab construction is widely used in most major centers of population, underfloor-plenum construction would be considered by many of the respondents as a good alternative (9).

The research was then expanded to include several other major cities and their surrounding counties from coast to coast. To provide a comprehensive evaluation of the findings, the data from three of the city-county areas studied in Florida—Jacksonville, St. Petersburg, and Miami—were analyzed in conjunction with data from 21 other areas from coast to coast across the Southern United States (fig. 12). The cities and counties that comprise the San Francisco-East Bay Area (Martinez in Contra Costa County and Oakland in Alameda County) were included in the survey, as were the counties in the Atlanta metropolitan area (Fulton and DeKalb). Because the questionnaires from builders and architects indicated that most single-family homes in Louisville, Nashville, and

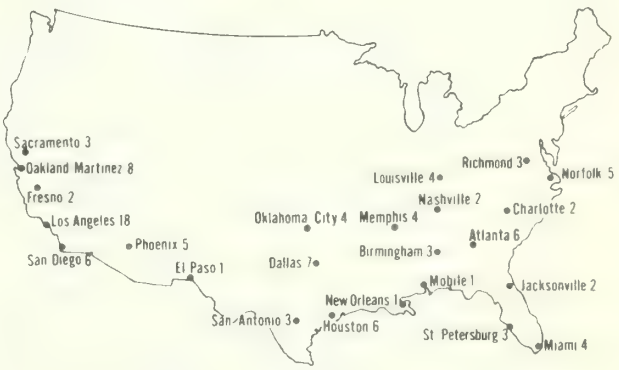


Figure 12.—Market areas selected for evaluation of preferences as to types of floor construction. Numbers (in thousands) indicate the average annual number of one-unit housing permits issued in the cities and surrounding counties from 1963 through 1967.

Richmond are built over basements, new home buyers in these areas were not questioned.

The market evaluation was based on the responses of architects and builders who design or build one-story, single-family homes and buyers who purchased new single-family homes since 1963. The survey totals were as follows:

	Number questioned	Number who responded	Number suitable for evaluation
Architects	763	601	321
Builders	957	664	498
New home buyers	3,597	1,920	1,680

Characteristics of New Homes in Areas Surveyed

Cost of Most New Homes Over $22,000

The new home buyers responding to this survey were definitely not in the low-cost housing market (fig. 13A). However, comparison

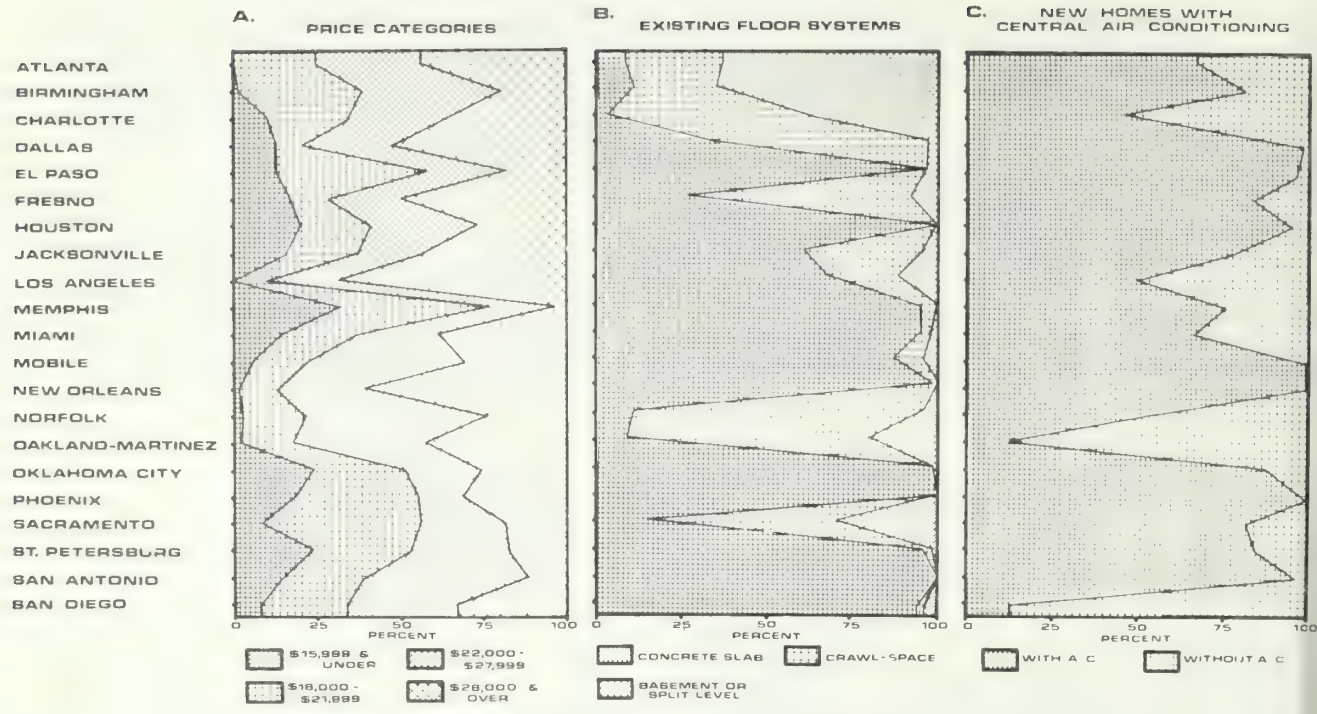


Figure 13.—(A) Approximate percentage of new homes purchased in each of four price categories in 21 selected market areas. (B) Type of floor construction in new homes in 21 selected market areas. (C) Percentage of new homes with central air conditioning in 21 selected market areas.

with data from the Bureau of the Census indicated that these respondents can be considered typical of new home buyers in the areas studied (*29*).

Most Areas Dominated by Slab Construction

Approximately 65 percent of the responding buyers purchased homes with slabs, while about 22 percent purchased homes with crawl-space construction (fig. 13B). Split-level or basement construction accounted for another 12 percent of the respondents. The predominant use of slab construction was expected in many of the areas selected for this study.

Most Homes Equipped with Central Air Conditioning

Over 70 percent of the homes purchased by the respondents were equipped with central air conditioning (fig. 13C). There were only two areas where central air conditioning was not common—San Diego and Oakland-Martinez. Areas near the Pacific coast have very moderate summer temperatures. About 50 percent of the homes purchased in the Los Angeles-Orange County area had central air conditioning. This percentage is higher than that for San Diego because Los Angeles County is quite large and the sample included inland areas away from the coast. In contrast, central air conditioning was installed in almost all new houses in Texas and the southern coastal area. With the exception of those on the California coast, at least 90 percent of the respondents indicated a desire for central air conditioning in a future house. Therefore, the underfloor-plenum method of air distribution could be an important design feature in new home construction in most of the geographic areas evaluated.

Factors Involved in Choosing Between Slab and Crawl-Space

The pilot study in Florida revealed that, in approximately three out of four cases, the builder decided what type of floor system would be used in the new house. In the comprehensive evaluation, it was found that the builder decided on the basic design in approximately 60 percent of the homes purchased (fig. 14A). The home buyer seldom made the basic design decision. The architect or professional designer sometimes influenced the basic design but not nearly as often as the builder.

Builders, architects, and new home buyers were asked to indicate their preferences for slab or crawl-space construction. The preference varied among areas and among the three groups in the same area (fig. 14B). However, the important contrast is between the builders and

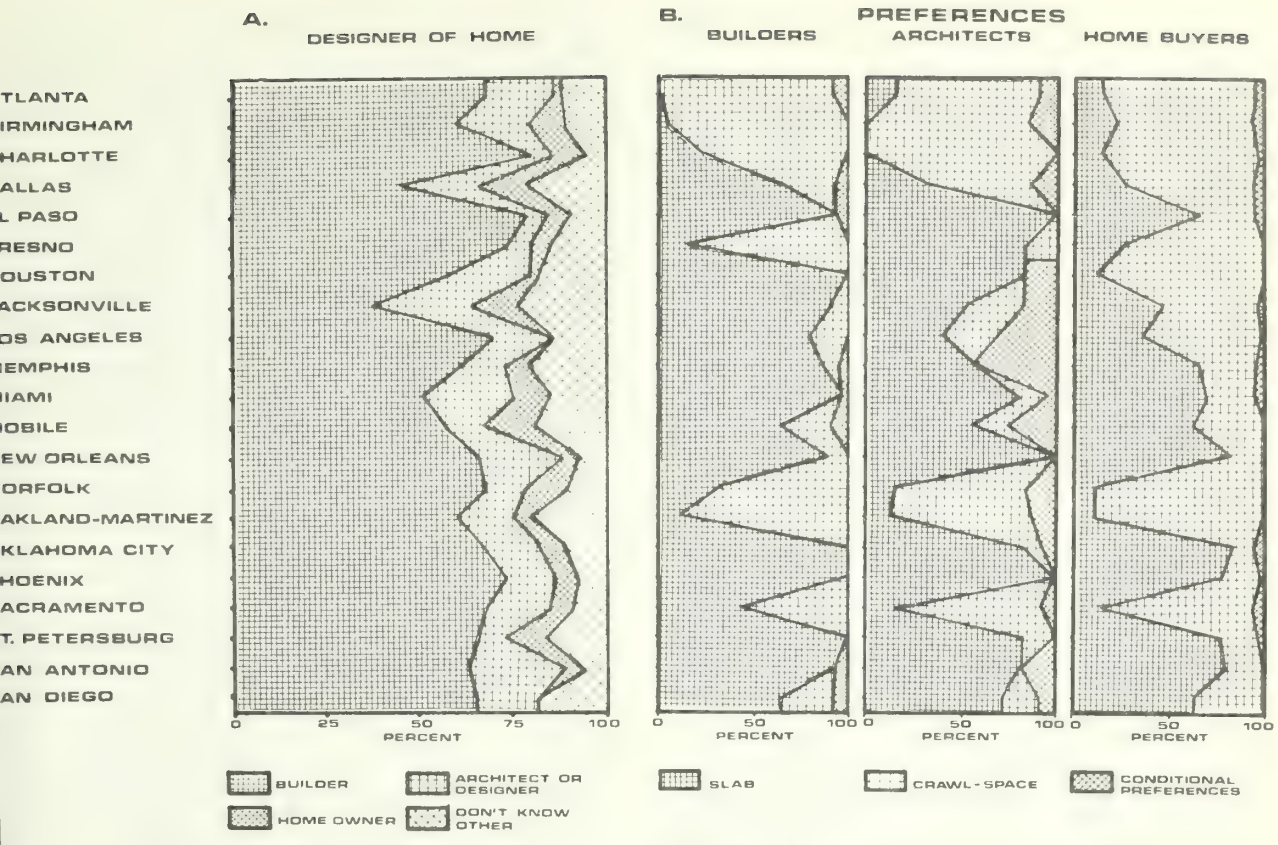


Figure 14.—(A) Individual responsible for the design of new homes in 21 selected market areas. (B) Type of floor construction preferred by builders, architects, and new home buyers in 21 selected market areas. Conditional preferences indicate that the respondent's decision to use slab or crawl-space usually depends on the individual site and home design.

ew home buyers, because the builder's prefer-nce is likely to determine the design selected espite the contrary preference of the buyer. or example, rather large differences in prefer-ce were found between builders and buyers in allas, El Paso, Houston, Jacksonville, Los ngeles, Miami, and Sacramento. In all of these cations, the new home buyers expressed a uch stronger preference for crawl-space con-truction than did the builders.

Lists of advantages and disadvantages associ-ed specifically with the use of concrete-slab d crawl-space construction were given to ch of the three survey groups. Each group was ked to select the three most important advan-ges and the three most important disadvantages y associated with the two types of floor nstruction.

dvantages of Concrete Slab

The builders indicated there are several advan-ges of slab construction which are almost cial in importance: cost, low-profile appear-nce, indoor-outdoor convenience, and predict-bility of performance. This combination of dvantages is impressive and explains why con-crete-slab construction is very competitive with the crawl-space system.

The architects felt there are two important advantages associated with concrete slabs. One is the combination of easy indoor-outdoor access and the low-profile appearance of the house. The second most frequently cited advantage was cost. Thus, the architects and builders were in close agreement on what advantages are most important.

Builders and architects in some cities said they used concrete-slab construction because it could be modified to cope with the local soil conditions. Because of unstable soils, monolithic concrete slabs, heavily reinforced with steel, are used in the San Antonio area and in the areas around Dallas, Houston, and Oklahoma City. The expanding and contracting soils in San Antonio and surrounding Bexar County are more severe than in any other area surveyed. The peculiar soil problems which occur in this area when the moisture content of the soil changes are well documented (*31*). Monolithic concrete slabs reinforced with steel are also used in the New Orleans area and in some areas near Miami because of the swampy soil conditions

which would otherwise require extensive use of pilings under the houses.

The new home buyers were as cost conscious as the builders and architects, but they also felt that concrete-slab construction resulted in less floor maintenance as well as cooler floors in the summer.

Disadvantages of Concrete Slab

Builders generally agreed that the primary disadvantages of slab construction are poor access to piping, unsuitability for sloping sites, the fatigue produced by walking on concrete floors, and increased construction problems in wet weather. Architects also agreed that poor access to piping is an important disadvantage. Other important disadvantages cited by architects were problems with sloping sites and potential problems with cracks. The objections most frequently cited by new home buyers were poor access to piping, the fatigue produced by walking on concrete floors, and a potential problem with cracking.

Advantages of Wood Crawl-Space

As might be expected, many of the disadvantages associated with slab construction were often considered to be advantages of crawl-space construction. For example, the builders, architects, and new home buyers all selected good access to piping as the primary advantage of crawl-space construction. The builders and architects also frequently cited its suitability for sloping sites and the lack of fatigue from walking on wooden floors. New home buyers also cited the latter factor and the availability of attractive hardwood floors.

In the San Francisco-East Bay area, the respondents indicated that crawl-space construction allows easy underfloor access for the purpose of leveling the floors. Floor leveling is occasionally required because of the settling and shifting action of some soil types in the area, especially on steep hillsides.

Disadvantages of Wood Crawl-Space

Builders and architects were in complete agreement on the three most important disadvantages they associated with crawl-space construction. In descending order of importance, these were the difficulty in achieving a ground-hugging appearance, higher costs, and the necessity of providing steps up from the ground.

New home buyers cited a different group of disadvantages. Over 50 percent of them were concerned about termites, while 39 percent were concerned about roaches, ants, and other insects. Also, nearly 48 percent of the respondents thought that wood lacks permanence. Thus, much work needs to be done to make new home buyers aware of the chemical treatments which can be safely and properly applied to wood members and to the soil under the house in order to prevent damage by insects and decay organisms (*17, 22, 30*).

Market Potential for the Underfloor Plenum

In order to evaluate the market potential for the underfloor plenum, each person in the survey was asked to indicate whether he would consider using the plenum system. Then he was asked if he would consider using the system even if it were more costly than slab construction. The answers to these questions are summarized in table 3. The general response was favorable among all three groups questioned. However, the potential market acceptance of the plenum system by the builders was much stronger in some areas than in others.

Potential market acceptance of the plenum by the builders in each area was classified as good, fair, or poor on the basis of the following criteria:

Good—50 percent or more of the builders would consider using the plenum even if costs might be higher than for slab construction.

Poor—50 percent or more would not consider using the plenum even if it were competitive in cost with the slab.

Fair—Less than 50 percent of the builders were in either the good or poor categories. If the plenum were competitive in cost with the slab, it might be considered.

Table 3.--Responses of builders, architects, and new home buyers on whether they would consider using the underfloor plenum

Respondent	Would not consider plenum	No decision	Would consider even if cost more than slab	Would consider only if cost same as slab	Total acceptance
			Percent		
Builders	37	6	41	16	57
Architects	21	8	58	13	71
New home buyers	20	4	66	10	76

Responses in each area were classified according to these criteria (fig. 15).

Table 4 shows seven market areas where the builders' acceptance of the plenum system was fair or good and where the concrete slab is now the dominant type of floor construction in new homes. However, underfloor-plenum construction would be permitted by building code officials in only three of the seven major cities listed. The outlook as far as building codes are concerned is much better in the seven surrounding counties. The very important market area of Los Angeles County would not prohibit the underfloor plenum if it is similar to crawl-space construction with respect to clearance between the bottom of the joists and the ground vapor barrier and if ventilation is provided. Therefore, building codes would present a problem in only one of the seven counties shown—Dade County.

Table 5 shows six market areas where the builders' acceptance of the plenum system is expected to be good and where the crawl-space is now the dominant type of floor construction in new homes. (Oakland and Martinez are listed separately in order to show the differences in code restrictions between city and county jurisdictions.) Underfloor-plenum construction would be permitted by building code officials in most of the jurisdictions, but conflicting rulings were obtained from city and county officials in three market areas—Charlotte, Oakland, and Sacramento. Thus, builders in these areas who wished to construct homes with plenum systems would need to pay close attention to city-county boundaries. Such situations will continue to bring criticism to building codes and local code officials.

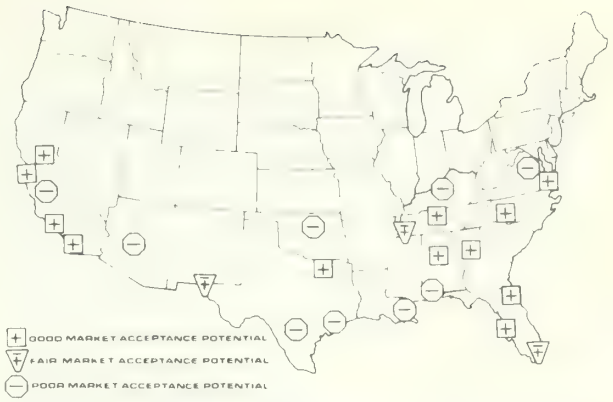


Figure 15.—Potential acceptance of underfloor-plenum construction in 24 U.S. markets.

Each individual in the survey was given an opportunity to write in what he thought might be advantages and disadvantages in building, designing, or living in a home with a wood floor and underfloor plenum for distribution of cool and warm air. These questions were completely open-ended. Thus, a variety of responses were received.

Table 4.--Areas dominated by slab construction but with fair or good market potentials for plenums

City and county	Homes purchased with slabs	Potential market acceptance	Plenum permitted by—		One-unit permits issued in city and county each year, 1963-67 [1]
			City code officials	County code officials	
	Percent				*Avg. number*
El Paso, El Paso	95	Fair	No	(2)	1,200
Jacksonville, Duval [3]	58	Good	Yes	Yes	2,000
Los Angeles, Los Angeles	68	Good	No	No	18,000
Memphis, Shelby	92	Fair	Yes	Yes	4,000
Miami, Dade	92	Fair	No	No	4,000
St. Petersburg, Pinellas	96	Good	Yes	Yes	3,000
San Diego, San Diego	97	Good	No	Yes	6,000

1 Based on data published by U.S. Bureau of the Census (*25, 26, 27, 28*).

2 The state does not permit counties to enact or adopt building codes.

3 City and county officials under one government.

Table 5.--Areas dominated by crawl-space construction but with good market potential for plenums

City and county	Homes purchased with crawl-space	Potential market acceptance	Plenum permitted by—		One-unit permits issued in city and county each year, 1963-67 1/
			City code officials	County code officials	
	Percent				*Avg. number*
Charlotte, Mecklenburg	60	Good	No	Yes	2,000
Dallas, Dallas	54	Good	Yes	(2/)	7,000
Martinez, Contra Costa	58	Good	Yes	Yes	4,000
Norfolk 3/	84	Good	Yes	(3/)	>500
Oakland, Alameda	78	Good	Yes	No	4,000
Sacramento, Sacramento	55	Good	No	Yes	3,261

1/ Based on data published by U.S. Bureau of the Census (*25, 26, 27, 28*).

2/ The state does not permit counties to enact or adopt building codes.

3/ Independent city.

Expected Advantages of Plenum Construction

The advantages cited by each group of respondents are listed below in descending order of importance:

Builders	Architects	New home buyers
Cost: installation and operating	Warm floors in winter	Better air distribution for heating and cooling
Better air distribution, especially for heating	Better air distribution, especially for heating	Hardwood floors more comfortable, good appearance
Sales appeal	Potentially lower cost because of ductwork savings	Lower construction and maintenance costs
Wood finish floors	Low-profile appearance	Floors warm in winter, cool in summer
Low-profile appearance		No ducts, free attic space
		Low-profile appearance

The builders, and to a lesser extent the architects, were optimistic about the cost savings that could result from this type of construction. They anticipated that much of the cost savings would result from the omission of ductwork normally required. Architects also cited warm floors as an expected advantage of plenum construction.

Cost savings were important to the new home buyers but not as important as a more efficient and comfortable air-conditioning system. The new home buyers frequently listed the possibility of improved air distribution for both heating and cooling as an important advantage.

Expected Disadvantages of Plenum Construction

In many areas, several builders, architects, and home buyers said they could see no advantages in an underfloor plenum. Many of these respondents indicated they would not consider using the system. In some areas, especially Fresno, San Antonio, New Orleans, and Oklahoma City, the underfloor plenum should not be used indiscriminately because of problems with soils.

The disadvantages to plenum construction cited by each group of respondents in the survey are listed below in descending order of importance:

Builders	Architects	New home buyers
Buyer resistance to change	Cost: installation and operation	Attack by termites and other insects
Cost: installation and operation	Air distribution	Air distribution
Building codes and financing	Dampness and condensation	Underfloor access
Dampness and condensation	Ground and surface water	Ground and surface water
Terrain and soil conditions	Attack by termites and other insects	Cost: installation and operation
Air distribution		
Labor not familiar with construction		

cal soil problems and local building codes are ost likely to limit the use of the underfloor enum. As with any type of floor-foundation nstruction, care should be taken in site selec-n and in meeting certain code specifications.

The builders in many areas were concerned out buyers' resistance to change and new eas. Many builders and architects were ssimistic about how competitively priced the enum system would be in comparison with the ncrete slab or the wood crawl-space. Many chitects and home buyers and some builders ced doubts about air distribution with the enum during the cooling cycle. New home yers and architects also raised questions about mite control. All of these objections point to e need for dissemination of the data on the mparative costs and performance of the enum and on proper chemical treatment of ls and wood members in those areas where e conditions are suitable for plenum construc-n.

Many new home buyers were also concerned out access to underfloor piping—despite the despread use of piping under concrete slabs. cause this problem is a concern of many home yers, builders using wood floors with the derfloor plenum should consider providing ess hatches at critical plumbing locations in kitchen and bath areas.

Dampness and water problems concerned all ee groups to some extent. Some respondents re concerned about dampness or condensa-n occurring in the plenum when it is used for ling. Testing at the University of Florida ngly indicates that dampness and condensa-n will not occur when the plenum system is in ration. A water problem is likely to occur y if the site is poorly located or poorly ned. On such sites, a water problem would bably occur regardless of the type of floor em used.

Summary on Market Preferences

A. Major reasons for the use of and preference for slab construction include low-profile appearance, easy indoor-outdoor access, and the assumption that installation cost is lower than for crawl-space or plenum construction. In some areas, monolithic floor-foundations of poured concrete, heavily reinforced with steel, are used because of adverse soil conditions.

B. Major reasons for the use and preference for wood crawl-space include good access to underfloor piping, adaptability to sloping sites, and the lack of fatigue from walking on wooden floors as compared with concrete floors. In some areas, crawl-space construction was also favored because of special soil conditions. Many home buyers indicated a strongly negative reaction toward wood crawl-space because of the threat of termites. This apprehension could be expected to carry over to any other type of wood-floor construction.

C. Expected advantages of underfloor-plenum construction were lower installation cost and perhaps lower operating cost, better air distribution for both heating and cooling, comfortable and attractive hardwood floors, and low-profile appearance. Plenum construction would be considered as an alternative to slab and crawl-space construction in many market areas. However, its actual use may depend largely on whether those individuals interested in using it can obtain sufficient information and assistance from manufacturers of wood products, field representatives of forest products associations, manufacturers of mechanical units, and other representatives of the building products industry—in addition to the research results published and distributed by the Forest Service and cooperating research organizations.

General Summary and Conclusions

esearch completed at the University of ida has shown that an underfloor-plenum em is feasible and practical for both cooling heating when incorporated in a single-family story house with wood-floor construction. distribution with the plenum is simple, yet it ides as much or more thermal comfort and rol than most other air-distribution systems in single-family houses. Plenum construc-permits the use of wood floors which are stiring to walk on than concrete floors. The profile design and easy indoor-outdoor s often associated with slab construction also be achieved. The cost of the plenum stm is estimated to be well within the competitive range of slab construction with comparable finish floors. The cost saving is largely due to the elimination of ductwork.

Many of the survey respondents thought that termites would pose a major threat to any type of wood-floor construction. This opinion was most often expressed by new home buyers. These studies indicate that considerable effort is necessary to educate the public regarding the effectiveness of termite prevention and control methods now available.

In some of the market areas, terrain and soil conditions influence the type of floor construc-

tion used in homes. In general, slab construction is used in flat terrain. Such terrain would also favor plenum construction. Specially designed slab construction is often used in San Antonio, Houston, Dallas, Oklahoma City, New Orleans, and southeast Florida because of the soil types found in these areas. However, crawl-space construction is favored in the San Francisco-East Bay area because of the sliding soils often found there.

The construction of single-family homes in areas where marginal building sites exist could cause problems with any type of floor-foundation. Plenum construction is not particularly different from crawl-space construction, but site selection and preparation should be carefully controlled, especially in areas known to have unusual soil conditions.

Building code regulations and their interpretation would prohibit or discourage the use of underfloor plenums in some areas. The Uniform Building Code requires the use of stub ducts when an underfloor plenum is used in homes. This requirement might discourage the use of the plenum in smaller houses where the cost savings in ductwork could be an important reason for using such construction. The Basic Building Code stipulates that a plenum chamber conform with the same minimum requirements as duct systems. A 2-hour fire-resistance rating is included in this requirement. The other two major codes used in the United States, the Southern Standard Building Code and the National Building Code, both permit the use of the underfloor plenum and have no requirements which would unduly restrict its use. Nevertheless, acceptance of the underfloor plenum is a prerogative of the local code officials because many communities add to or change their model codes. Some code officials who have raised questions about the plenum probably would permit its use if they were supplied with more complete test information about the system.

Although the plenum would be a good alternative to the slab or crawl-space in many areas of the United States, its adoption and widespread use is likely to come about slowly. A strong interest in the system definitely exists among architects and builders. New home buyers also seem willing to use it. As with most new ideas in the construction industry, however, its feasibility must be demonstrated locally. Local builders, architects, and new home buyers are not likely to adopt new ideas unless they have enough information to assure that these ideas have a reasonable chance of success. The findings summarized and cited in this paper have been documented for evaluation by people in research and in the construction industry and for those who may wish to incorporate some of these construction ideas in future houses.

Wood-floor construction with an underfloor plenum is not only feasible but can also provide a comfortable floor system at a reasonable cost to the new home buyer. It is a relatively flexible concept which can be modified to meet the specific design requirements of individuals in many localities.

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The underfloor plenum was evaluated as an alternative to floor-foundations composed of concrete slabs or wood crawl-spaces in one-story, single-family homes. This system proved to be a practical method of wood-floor construction when used with conventional year-round air-conditioning units. Local building codes and soil conditions would be the major restrictions to its use in some of the market areas evaluated in the South and Southwest. However, cost estimates indicate that underfloor-plenum construction would be competitive with the concrete slab in all areas evaluated, and in several areas the responses of architects, builders, and new home buyers indicated a good potential market for this system.

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The underfloor plenum was evaluated as an alternative to floor-foundations composed of concrete slabs or wood crawl-spaces in one-story, single-family homes. This system proved to be a practical method of wood-floor construction when used with conventional year-round air-conditioning units. Local building codes and soil conditions would be the major restrictions to its use in some of the market areas evaluated in the South and Southwest. However, cost estimates indicate that underfloor-plenum construction would be competitive with the concrete slab in all areas evaluated, and in several areas the responses of architects, builders, and new home buyers indicated a good potential market for this system.

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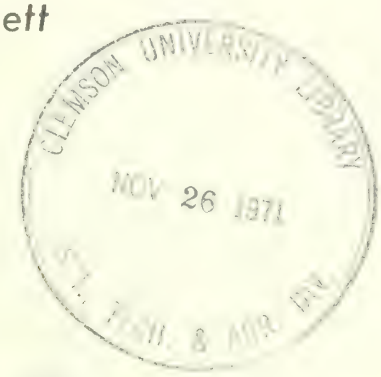
The Role of Thinning and Some Other Problems in Management of Slash Pine Plantations

by

Frank A. Bennett



U.S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
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The Role of Thinning and Some Other Problems in Management of Slash Pine Plantations

by

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In the management of slash pine (Pinus elliottii var. elliottii) plantations, the role of thinning is changing from the traditional concept associated with this silvicultural tool as developed in natural stands. In fact, for pulpwood production many owners are selecting spacings that will not require thinning during the rotation. Others insist that thinning must be financially advantageous even in pulpwood rotations, because an early recovery of establishment costs is thus obtained. Length of rotation, as related to growth rates, is also a point in question, and early liquidation may be a temptation to those unaware of production rates at various ages.

To help solve some of these problems, this paper outlines production figures at yearly intervals for unthinned slash pine plantations, assesses the possible effect of thinning on growth, and evaluates the role of thinning in the management of these plantings.

THE BASIC DATA

From sample data collected throughout the range of planted slash pine in Georgia and Florida, total cordwood yield for various combinations of age, site, and stand density were established at yearly intervals, beginning at age 10, by the diameter distribution technique employed by Bennett and Clutter.[1] Current annual cordwood growth was then established for ages 11 through 30 by subtracting the yield at each age from the following year's yield.

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[1] Bennett, Frank A., and Clutter, Jerome L. Multiple-product yield estimates for unthinned slash pine plantations--pulpwood, sawtimber, gum. Southeast. Forest Exp. Stn., U. S. Forest Serv. Res. Pap. SE-35, 21 pp. 1968.

In addition to yields, complete diameter distributions were established at each age, as were basal area values, crown ratio percentages, and heights for each diameter class. This detailed information is contained in a separate publication.[2]

GROWTH RELATIONSHIPS

On good sites, current annual increments (CAI) for cordwood are unbelievably high at certain ages because of ingrowth and excellent height growth (table 1). A decision to clearcut--for whatever reason--at an early age will sacrifice the stand's most productive years. For example, the mean annual increment (MAI) of 400 trees per acre on site 70 at age 25 is 1.97 cords per acre (table 2). Current annual increment for the same stand is 3 cords or better from age 11 through age 17. Further, a stand of 600 trees on site 70 shows an average annual increment of 3.87 cords from age 11 through age 18 but a mean annual increment of only 2.38 cords at age 25. Any decision to liquidate a stand prior to age 18 should take into consideration an annual growth rate that will be from 50 to 85 percent greater than the mean annual increment at age 25. The patterns of current and mean annual increment present a useful picture of the growth and development of the stand.

Current annual increment culminates at age 12 in 200-tree stands on all sites (table 1). Culmination occurs later for higher densities but never later than age 15, except on site 50 for stands above 400 trees per acre. Culmination does not occur at the peak periods of height growth. According to calculations, height growth declines after age 10 for all sites and densities. Furthermore, investigation of diameter distributions shows culmination occurs after the peak period of ingrowth. Ingrowth declines after age 10 on all sites and for all densities.

Basal areas at culmination also vary widely, from 42 square feet for a 200-tree stand on site 50 to 155 feet for an 800-tree stand on site 80 (table 3). The two stands differ in age by only 1 year. Basal area at culmination within site also varies considerably: the square footage for the 200-tree stand is only 41 to 46 percent of that for the 800-tree stand. These facts seem to indicate that basal area *per se* has little direct effect on CAI culmination; and in some stands ingrowth would seem to have little influence. For example, on sites 70 and 80, diameter distributions show there are no trees below merchantable size (4.6 inches at d.b.h.) at CAI culmination in the 200-tree stands. Diameter and height growth interact with tree size, as determined by age, site index, and density, to bring about culmination. For a given stand, a particular combination of growth rates and diameter distribution results in maximum volume growth per acre. For example, the average crown ratio at culmination for the 200-tree stand on site 60 is 69 percent, whereas the average for the 800-tree stand on site 60 is 41 percent (table 3).

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[2] Bennett, Frank A. Yields and stand structural patterns for old-field plantations of slash pine. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-60, 81 pp. 1970.

Table 1.--Current annual increments (CAI) for cordwood of slash pine plantations at various ages, density classes, and site indices

SITE INDEX 50[1]

Age	Trees per acre						
	200	300	400	500	600	700	800
	Cords per acre						
11	1.11	1.15	1.07	1.00	0.95	0.91	0.91
12	1.20	1.30	1.33	1.29	1.26	1.24	1.22
13	1.18	1.37	1.45	1.48	1.47	1.46	1.45
14	1.20	1.41	1.50	1.56	1.59	1.60	1.61
15	1.17	1.37	1.54	1.61	1.66	1.68	1.69
16	1.13	1.37	1.51	1.62	1.67	1.72	1.74
17	1.10	1.33	1.48	1.60	1.68	1.72	1.76
18	1.06	1.28	1.45	1.56	1.66	1.72	1.76
19	1.01	1.23	1.41	1.52	1.61	1.68	1.73
20	0.96	1.19	1.36	1.49	1.57	1.65	1.70
21	0.94	1.15	1.30	1.43	1.52	--	--
22	0.89	1.11	1.25	1.39	1.48	--	--
23	0.85	1.05	1.21	1.33	1.44	--	--
24	0.82	1.01	1.16	1.28	1.38	--	--
25	0.77	0.96	1.12	1.23	1.33	--	--
26	0.73	0.92	1.07	1.18	--	--	--
27	0.71	0.89	1.03	1.13	--	--	--
28	0.68	0.85	0.99	1.10	--	--	--
29	0.65	0.81	0.95	1.05	--	--	--
30	0.63	0.79	0.91	1.01	--	--	--

SITE INDEX 60[1]

11	1.68	1.94	2.09	2.17	2.20	2.25	2.28
12	1.73	2.06	2.27	2.40	2.50	2.57	2.65
13	1.71	2.07	2.34	2.53	2.66	2.77	2.85
14	1.70	2.09	2.34	2.56	2.74	2.86	2.98
15	1.66	2.02	2.34	2.55	2.73	2.89	3.01
16	1.59	1.98	2.27	2.52	2.70	2.86	2.99
17	1.55	1.93	2.21	2.46	2.66	2.82	2.97
18	1.49	1.85	2.14	2.37	2.59	2.76	2.90
19	1.41	1.77	2.07	2.30	2.50	2.68	2.83
20	1.35	1.70	2.00	2.23	2.42	2.59	2.74
21	1.31	1.65	1.90	2.14	2.33	--	--
22	1.24	1.57	1.82	2.06	2.25	--	--
23	1.19	1.50	1.76	1.98	2.16	--	--
24	1.13	1.43	1.68	1.89	2.09	--	--
25	1.07	1.36	1.62	1.81	2.00	--	--
26	1.03	1.31	1.55	1.74	--	--	--
27	0.98	1.26	1.49	1.67	--	--	--
28	0.94	1.20	1.42	1.61	--	--	--
29	0.91	1.16	1.36	1.54	--	--	--
30	0.86	1.11	1.30	1.48	--	--	--

[1] 25-year basis.

Table 1.--Current annual increments (CAI) for cordwood of slash pine plantations at various ages, density classes, and site indices (continued)

SITE INDEX 70[1]

Age	Trees per acre						
	200	300	400	500	600	700	800
	Cords per acre						
11	2.33	2.80	3.18	3.44	3.65	3.85	4.01
12	2.34	2.90	3.29	3.63	3.91	4.14	4.35
13	2.34	2.88	3.35	3.70	4.01	4.27	4.51
14	2.29	2.87	3.30	3.71	4.03	4.31	4.57
15	2.24	2.79	3.26	3.63	3.97	4.28	4.54
16	2.14	2.71	3.18	3.57	3.90	4.20	4.47
17	2.08	2.63	3.06	3.46	3.80	4.10	4.37
18	2.00	2.53	2.96	3.34	3.68	3.98	4.25
19	1.90	2.41	2.86	3.22	3.56	3.85	4.11
20	1.81	2.32	2.74	3.10	3.41	3.71	3.98
21	1.73	2.22	2.63	2.98	3.29	--	--
22	1.67	2.13	2.51	2.86	3.16	--	--
23	1.58	2.04	2.40	2.75	3.03	--	--
24	1.52	1.94	2.31	2.62	2.92	--	--
25	1.43	1.85	2.21	2.52	2.80	--	--
26	1.37	1.77	2.12	2.40	--	--	--
27	1.31	1.69	2.03	2.31	--	--	--
28	1.25	1.63	1.94	2.21	--	--	--
29	1.21	1.56	1.87	2.13	--	--	--
30	1.15	1.49	1.78	2.04	--	--	--

SITE INDEX 80[1]

11	3.05	3.80	4.37	4.87	5.30	5.69	6.03
12	3.09	3.85	4.50	5.04	5.51	5.93	6.33
13	3.08	3.86	4.50	5.06	5.57	6.03	6.44
14	3.00	3.79	4.46	5.03	5.54	6.00	6.42
15	2.92	3.72	4.35	4.94	5.45	5.92	6.35
16	2.83	3.58	4.24	4.80	5.31	5.78	6.22
17	2.69	3.46	4.11	4.65	5.15	5.61	6.04
18	2.60	3.33	3.94	4.50	4.99	5.43	5.85
19	2.49	3.20	3.78	4.33	4.81	5.24	5.65
20	2.37	3.05	3.64	4.14	4.62	5.06	5.44
21	2.25	2.91	3.50	3.98	4.43	--	--
22	2.15	2.79	3.34	3.84	4.25	--	--
23	2.05	2.67	3.19	3.66	4.08	--	--
24	1.97	2.56	3.04	3.52	3.91	--	--
25	1.88	2.44	2.92	3.36	3.76	--	--
26	1.78	2.33	2.79	3.21	--	--	--
27	1.70	2.21	2.68	3.08	--	--	--
28	1.62	2.12	2.57	2.94	--	--	--
29	1.55	2.04	2.46	2.83	--	--	--
30	1.49	1.95	2.36	2.71	--	--	--

[1] 25-year basis.

Table 2.--Mean annual increments (MAI) for cordwood of slash pine plantations at various ages, density classes, and site indices

SITE INDEX 50[1]

Age	Trees per acre						
	200	300	400	500	600	700	800
	Cords per acre						
10	0.15	0.11	0.08	0.07	0.06	0.06	0.06
11	0.24	0.20	0.17	0.15	0.14	0.14	0.14
12	0.32	0.29	0.27	0.25	0.24	0.24	0.24
13	0.38	0.38	0.36	0.34	0.33	0.33	0.33
14	0.44	0.45	0.44	0.43	0.42	0.42	0.42
15	0.49	0.51	0.51	0.51	0.51	0.51	0.51
16	0.53	0.56	0.58	0.58	0.58	0.58	0.58
17	0.56	0.61	0.63	0.64	0.64	0.65	0.65
18	0.59	0.65	0.67	0.69	0.70	0.71	0.71
19	0.61	0.68	0.71	0.73	0.75	0.75	0.75
20	0.63	0.70	0.75	0.77	0.79	0.80	0.81
21	0.64	0.72	0.77	0.80	0.82	--	--
22	0.66	0.74	0.79	0.83	0.85	--	--
23	0.66	0.76	0.81	0.85	0.88	--	--
24	0.67	0.77	0.83	0.87	0.90	--	--
25	0.67	0.77	0.84	0.88	0.92	--	--
26	0.68	0.78	0.85	0.89	--	--	--
27	0.68	0.78	0.85	0.90	--	--	--
28	0.68	0.79	0.86	0.91	--	--	--
29	0.68	0.79	0.86	0.91	--	--	--
30	0.68	0.79	0.86	0.92	--	--	--

SITE INDEX 60[1]

10	0.33	0.31	0.28	0.27	0.27	0.28	0.29
11	0.45	0.46	0.45	0.44	0.44	0.45	0.48
12	0.56	0.59	0.60	0.60	0.61	0.63	0.66
13	0.66	0.70	0.73	0.75	0.77	0.80	0.83
14	0.72	0.80	0.85	0.88	0.91	0.94	0.98
15	0.79	0.88	0.96	0.99	1.03	1.07	1.11
16	0.83	0.95	1.03	1.09	1.14	1.18	1.23
17	0.88	1.01	1.10	1.17	1.23	1.28	1.33
18	0.91	1.06	1.16	1.24	1.30	1.36	1.42
19	0.94	1.09	1.21	1.29	1.37	1.43	1.50
20	0.96	1.12	1.24	1.34	1.42	1.49	1.56
21	0.98	1.15	1.28	1.38	1.46	--	--
22	0.99	1.17	1.30	1.41	1.50	--	--
23	1.00	1.18	1.32	1.43	1.53	--	--
24	1.00	1.19	1.34	1.45	1.55	--	--
25	1.00	1.20	1.35	1.47	1.57	--	--
26	1.00	1.20	1.35	1.48	--	--	--
27	1.00	1.21	1.36	1.48	--	--	--
28	1.00	1.21	1.36	1.49	--	--	--
29	0.99	1.20	1.36	1.49	--	--	--
30	0.99	1.20	1.36	1.49	--	--	--

[1] 25-year basis.

Table 2.--Mean annual increments (MAI) for cordwood of slash pine plantations at various ages, density classes, and site indices (continued)

SITE INDEX 70[1]

Age	Trees per acre						
	200	300	400	500	600	700	800
	Cords per acre						
10	0.57	0.59	0.60	0.61	0.63	0.67	0.71
11	0.73	0.79	0.83	0.87	0.91	0.96	1.01
12	0.86	0.97	1.04	1.10	1.16	1.22	1.29
13	0.97	1.11	1.22	1.30	1.38	1.46	1.54
14	1.07	1.24	1.37	1.47	1.57	1.66	1.75
15	1.15	1.34	1.49	1.62	1.73	1.83	1.94
16	1.21	1.43	1.60	1.74	1.86	1.98	2.10
17	1.26	1.50	1.68	1.84	1.98	2.11	2.23
18	1.30	1.56	1.75	1.92	2.07	2.21	2.34
19	1.33	1.60	1.81	1.99	2.15	2.30	2.44
20	1.36	1.64	1.86	2.04	2.21	2.37	2.51
21	1.37	1.66	1.90	2.09	2.26	--	--
22	1.39	1.69	1.92	2.13	2.31	--	--
23	1.40	1.70	1.94	2.15	2.34	--	--
24	1.40	1.71	1.96	2.17	2.36	--	--
25	1.40	1.72	1.97	2.19	2.38	--	--
26	1.40	1.72	1.98	2.19	--	--	--
27	1.40	1.72	1.98	2.20	--	--	--
28	1.39	1.71	1.98	2.20	--	--	--
29	1.39	1.71	1.97	2.20	--	--	--
30	1.38	1.70	1.97	2.19	--	--	--

SITE INDEX 80[1]

10	0.85	0.95	1.02	1.09	1.16	1.24	1.33
11	1.05	1.21	1.33	1.43	1.53	1.64	1.76
12	1.22	1.43	1.59	1.73	1.87	2.00	2.14
13	1.37	1.62	1.83	1.99	2.15	2.31	2.47
14	1.48	1.77	2.00	2.21	2.39	2.57	2.75
15	1.58	1.90	2.16	2.39	2.60	2.80	2.99
16	1.66	2.01	2.29	2.54	2.77	2.98	3.19
17	1.72	2.09	2.40	2.66	2.91	3.14	3.36
18	1.77	2.16	2.48	2.77	3.02	3.26	3.50
19	1.81	2.22	2.55	2.85	3.12	3.37	3.61
20	1.83	2.26	2.61	2.91	3.19	3.45	3.70
21	1.85	2.29	2.65	2.96	3.25	--	--
22	1.87	2.31	2.68	3.00	3.30	--	--
23	1.87	2.33	2.70	3.03	3.33	--	--
24	1.88	2.34	2.72	3.05	3.35	--	--
25	1.88	2.34	2.72	3.06	3.37	--	--
26	1.88	2.34	2.73	3.07	--	--	--
27	1.87	2.34	2.73	3.07	--	--	--
28	1.86	2.33	2.72	3.06	--	--	--
29	1.85	2.32	2.71	3.06	--	--	--
30	1.84	2.31	2.70	3.04	--	--	--

[1] 25-year basis.

Table 3.--Stand conditions at culmination of current annual increment

Trees per acre	Age	Basal area per acre	Mean diameter	Mean crown ratio[2]
	Years	Sq. ft.	Inches	Percent
SITE INDEX 50[1]				
200	12	42	6.2	73
400	15	70	5.7	53
600	17	91	5.3	43
800	17	101	4.8	40
SITE INDEX 60[1]				
200	12	52	6.9	69
400	13	77	5.9	56
600	14	99	5.5	47
800	15	113	5.3	41
SITE INDEX 70[1]				
200	12	63	7.5	67
400	13	93	6.5	54
600	14	122	6.1	45
800	14	140	5.7	41
SITE INDEX 80[1]				
200	12	70	8.0	64
400	12	99	6.7	55
600	13	133	6.4	45
800	13	155	6.0	41

[1] 25-year basis.
[2] Percent of total height occupied by green crown in the average tree.

Mean annual increment varies from 0.15 cord for 200 trees on site 50 at age 10 to 3.70 cords for 800 trees on site 80 at age 20 (table 2). The data permitted calculation of yields to age 30 for stands of only 500 trees per acre or less. Thus, points of culmination could not be ascertained for stands of higher density. The growth pattern of the stands at higher densities indicates they are approaching culmination, because mean annual increment increases by only 0.02 to 0.09 cord the last year for which growth values are listed.

As outlined in table 2, age at culmination varies from 23 to 30 years, depending on site and stocking. However, for a period of 3 to 4 years just prior to culmination, MAI is practically static, increasing at the rate of 0.01 to 0.02 cord (0.9 to 1.8 cubic feet) per acre annually.

As with CAI, MAI culmination appears to be independent of basal area. Data for site index 70 will serve as an illustration:

Trees per acre (Number)	Age at culmination (Years)	Basal area at culmination (Square feet)
200	25	106
300	26	134
400	27	157
500	27	179

As number of trees per acre increases, basal area at culmination increases rapidly, but there is only a slight variation in age. For example, culmination in the 200-tree stand occurs at age 25 and 106 square feet of basal area, whereas culmination in the 500-tree planting occurs at age 27 and 179 square feet of basal area.

As would be expected, the age at which the CAI and MAI curves coincide varies with site and with density within site (fig. 1). Purely from the standpoint of maintaining stand vigor, thinning would not be required in any of these plantings until, or shortly before, the curves intersect. Under this premise, none of the stands would require thinning until age 23 and some not until age 30. Basal areas vary widely, of course, at the time the growth curves intersect, as illustrated below:

Site index	Trees per acre		
	200	400	600
	(Basal area in square feet)		
50	78	113*	134*
60	94	137	167*
70	106	157	198*
80	119	178	223*

*Extrapolated value.

The high densities on the better sites seem to imply a need for thinning prior to coincidence of the growth curves. However, thinning at an earlier age will not necessarily increase total cubic yield. In fact, chances are that cordwood yield will be reduced by thinning. The analysis in table 4 illustrates this point.

The commercial thinning, being concentrated in the lower diameter classes, left the dominant and faster growing trees. Even so, the residual stand, which averages 6.2 inches in diameter and has an average crown ratio of 42 percent, does not compare favorably with the

unthinned 400-tree stand. Even if only the trees 5 inches and above are considered, the average crown ratio of the thinned stand is still less than 44 percent. In comparison, the unthinned 400-tree stand at the same age averages 6.9 inches in diameter and has an average crown ratio of 47 percent.

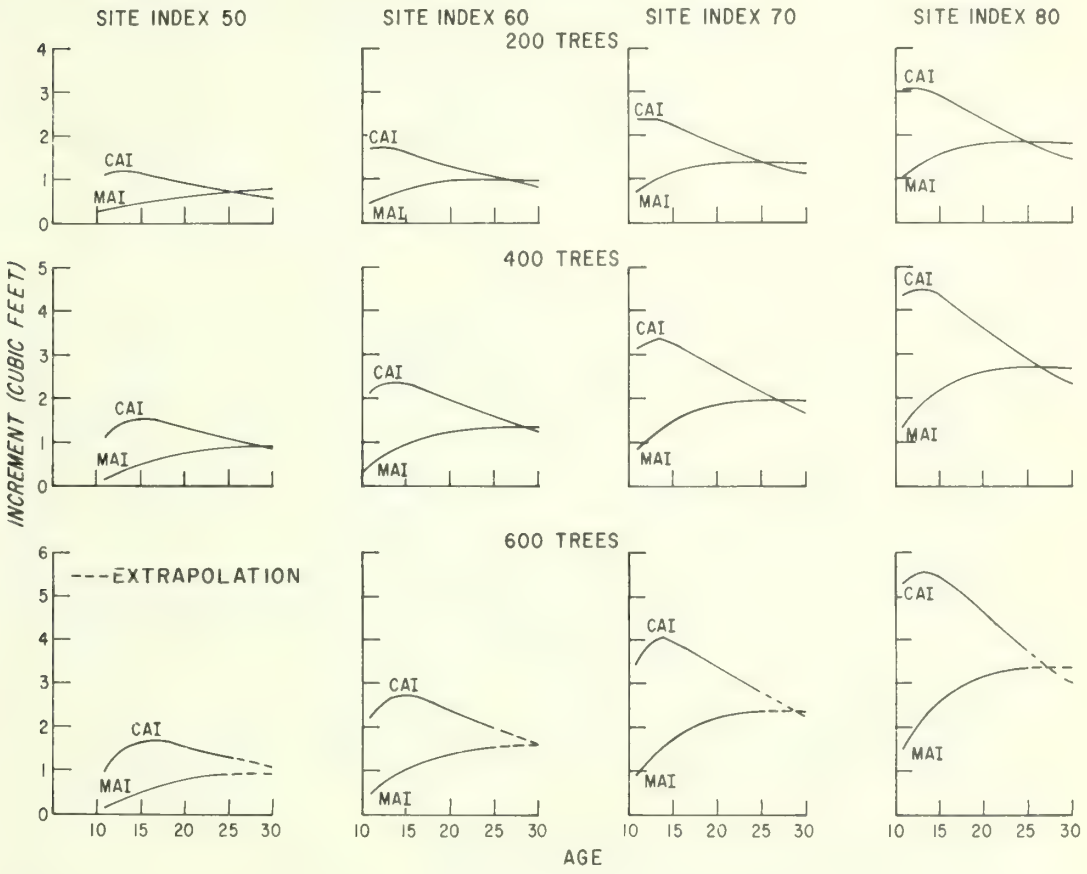

Figure 1.--Current (CAI) and mean (MAI) annual increments in cubic feet for slash pine plantations at various ages, density classes, and site indices.

As seen in table 1, the average annual increments on site 70 during the 5-year period from 16 to 20 years are 3.67 cords for the unthinned 600-tree stand and 2.96 cords for the 400-tree stand. The growth rate of the residual 400-tree stand during this period would have to exceed that of the unthinned 400-tree stand by almost 25 percent in order not to show a loss in volume growth as a result of thinning. This result does not seem likely. The thinned 400-tree stand will do well to equal the growth rate of the unthinned 400-tree stand, because it will start the period with 20 percent of the trees under 5 inches and a lower average crown ratio.

Table 4.--Comparison of a 600-tree stand, before and after thinning, at age 15 on site 70 with an unthinned 400-tree stand at age 15 on site 70

Diameter class	Original 600-tree stand				Timber cut from stand			Residual stand				400-tree stand				
	Trees	Basal area	Volume	Crown ratio	Trees	Basal area	Volume	Trees	Basal area	Volume	Crown ratio	Diameter class	Trees	Basal area	Volume	Crown ratio
Inches	No.	Sq. ft.	Cords	Percent	No.	Sq. ft.	Cords	No.	Sq. ft.	Cords	Percent	Inches	No.	Sq. ft.	Cords	Percent
1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
2	1	0.02	0	30.7	0	0	0	1	0.02	0	30.7	2	0	0	0	0
3	17	0.83	0	33.4	0	0	0	17	0.83	0	33.4	3	2	1.47	0	38.1
4	63	5.50	0	36.1	0	0	0	63	5.50	0	36.1	4	18	1.57	0	40.5
5	119	16.23	2.37	38.8	82	11.18	1.63	37	5.05	0.74	38.8	5	51	6.96	0.95	42.9
6	151	29.64	5.62	41.5	70	13.74	2.60	81	15.90	3.02	41.5	6	86	16.88	3.02	45.3
7	140	37.42	8.18	44.3	35	9.36	2.04	105	28.07	6.14	44.3	7	103	27.53	5.68	47.7
8	87	30.37	7.24	47.0	10	3.49	0.83	77	26.88	6.41	47.0	8	89	31.07	7.11	50.1
9	22	9.72	2.52	49.7	3	1.30	0.34	19	8.39	2.18	49.7	9	46	20.32	4.99	52.5
10	0	0	0	0	0	0	0	0	0	0	0	10	5	2.73	0.67	54.9
												11	0	0	0	0
Totals	600	129.73	25.93	--	200	39.07	7.44	400	90.64	18.49	--	--	400	108.53	22.42	--
		Weighted mean 41.9							Weighted mean 42.2					Weighted mean 47.4		
	Mean diameter = 6.1 inches							Mean diameter - 6.2 inches					Mean diameter = 6.9 inches			

The example cited involved thinning at the peak of current annual increment. The same relationships hold at older ages. It seems evident that, as long as mortality is not a factor, thinning is not likely to increase total cubic yield because cubic volume increment is a function of number of trees per acre. Past work has shown that thinning prior to any mortality losses has little effect on total cubic yield.[3] [4]

This being true, the objective of thinning in plantations resolves itself into one or more of the following considerations:

1. Early recovery of establishment costs
2. Reduction of the investment in growing stock
3. An increase in quality as measured by tree size
4. Sanitation and salvage.

If pulpwood is the product objective, the value of thinning is questionable for stands of medium density. For example, if we assume the residual stand would grow at the same rate as an unthinned planting of the same density from age 16 through age 25, total yield and return for thinned and unthinned plantations would be as in table 5.

When the three plantings were thinned, each had about 130 square feet of basal area; the 600- and 500-tree stands were cut to 400 trees per acre and the 400-tree stand was cut to 300. In each instance, and under the assumed condition, total wood yield was greater in the unthinned plantations; the thinned stand in the 500-tree planting did show a slightly greater total return. However, no charge for marking the stands for thinning was included. The stands could be thinned at younger ages, but heavier thinning, especially in the dominant stand, would be required to make an attractive cut. Such thinning, along with the greater reduction in number of trees per acre, would reduce subsequent growth.

A very high interest rate on the thinning return could force the total return from the thinned stand at rotation age above that of the unthinned plantation. However, strictly on a dollar-return basis, a rate high enough to exert such force probably would dictate liquidation of the planting at age 15 rather than a thinning, unless the owner were willing to gamble on a somewhat higher stumpage price at age 25 than at age 15.

If the owner chooses to make an investment charge on the base growing stock (cordwood volume) beginning at the time of thinning, the thinned stand will then show a greater return at rotation age. However, an investment charge on the base stocking could force early and frequent thinnings or an early liquidation of the stand.

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[3] Engle, Lamont G., and Smith, Norman F. Red pine growth ten years after thinning. Mich. Acad. Sci., Arts & Lett. 36: 101-109. 1952.

[4] Wakeley, Philip C. Single commercial thinnings in variously spaced slash and loblolly pine plantations. South. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SO-48, 12 pp. 1969.

Table 5.--Comparison of total wood yield and return for thinned and unthinned stands on site 70 (25-year basis)

Plantation	Thinning return		Harvest return		Total return[1]	
	Cords	Dollars	Cords	Dollars	Cords	Dollars
600-TREE STAND						
Unthinned	0	0	59.47	[2]535.23	59.47	535.23
Thinned (age 15)	7.44	[3]106.60	45.34	[2]408.06	52.78	514.66
Difference					6.69	20.57
500-TREE STAND						
Unthinned	0	0	54.56	[2]491.94	54.46	491.94
Thinned (age 17)	8.62	[3]109.92	43.27	[2]389.43	51.89	499.35
Difference					2.57	-7.41
400-TREE STAND						
Unthinned	0	0	49.24	[2]443.16	49.24	443.16
Thinned (age 19)	6.06	[3]68.79	40.88	[2]367.92	46.94	436.71
Difference					2.30	6.45

[1] Compounded establishment and management costs are not deducted because they would be the same for thinned and unthinned stands.

[2] At $9.00 per cord.

[3] At $8.00 per cord and an interest rate of 6 percent on the thinning return.

The question remains as to whether the owner would benefit by paying off his establishment cost after thinning. The answer really depends on interest rates. If he cannot get more interest on his thinning return than he is paying on the establishment cost, then he should pay it off; if he can get more interest than he is paying on the establishment cost, then he should take the alternative investment and carry the cost to the end of rotation. It is entirely possible, of course, that interest rates would be higher at time of thinning than 15 years earlier (witness present rates as opposed to those 15 years ago).

The foregoing analysis applies only when cordwood is the product objective. Thinning would stimulate saw-log and veneer production. However, if these products are the primary production goal, a wide spacing should be employed initially. In our example of the 600-tree planting, if the thinned stand produced sawtimber at the rate of unthinned plantings of the same stocking during the various growth periods and if thinning were to 400 trees at age 15, to 300 at age 20, and to 200 at age 25, then total yield at age 30 for the 600-tree planting would be 7,892 board feet. Total yield for an unthinned 200-tree stand at age 30 is 9,924 board feet (table 6). These same general relationships would seem to hold for veneer production. Projected diameter distributions show the thinning could be made at each interval without cutting 10-inch

Table 6.--Current annual increments and total yield at age 30 on site 70 for various stand densities

Age	Trees per acre					
	100	200	300	400	500	600[1]
	Board feet					
10	22	0	0	0	0	0
11	164	0	0	0	0	0
12	345	50	0	0	0	0
13	455	204	17	0	0	0
14	519	355	134	14	0	0
15	545	483	264	103	22	0
16	559	554	384	217	96	35
17	548	611	490	314	188	99
18	538	645	561	408	272	174
19	528	652	601	487	347	242
20	508	649	634	544	417	304
21	485	646	657	582	475	363
22	465	638	667	605	519	412
23	448	623	667	622	550	455
24	430	604	659	634	569	487
25	412	583	645	640	581	511
26	392	560	632	640	589	527
27	374	543	621	635	594	538
28	355	526	606	626	596	544
29	341	508	592	614	595	545
30	326	490	575	602	589	546
Total yield	8,759	9,924	9,406	8,287	6,999	5,782

[1] Growth beyond age 25 for the 600-tree stand is extrapolated beyond the range of sample data.

trees, the minimum size for sawtimber. As supporting evidence, the diameter distributions for a 200-tree stand at age 30 on site 70 shows 38 percent of the trees to be below 10 inches.[5]

These illustrations strongly suggest that, if the grower has a specific product objective, at the time of establishment he should choose a spacing tailored to this special need and not rely on intermediate thinnings as a device to develop the product. This idea does not, of course, obviate the usefulness of sanitation and salvage measures, the value of thinning in existing plantations with excess stocking, nor the need for periodic reductions in stocking with long rotations. But even in relatively long rotations in which the primary objective is large products, the greatest total yield will be produced by establishing relatively few trees per acre and using little thinning, as opposed to denser stands with more frequent and heavier thinning.

As to quality, it has been demonstrated that close spacings are not necessary for the production of timbers that qualify as dense structural material on the basis of ring count per inch, and that the final crop trees in such spacings will have knotty cores 7, 8, and 9 inches

[5] Ibid.

in diameter.[6] In comparison, calculations indicate the knotty core of the final crop trees in a stand of 400 trees per acre will average less than 9.0 inches in diameter. Increased board-foot production in the wider spacing will tend to offset the advantage of the slightly smaller knotty core in the heavier stand. Also, a shorter rotation will be required to produce trees of a given size.

Simply stated, in plantation management oriented around products, product objective should determine initial spacing; and, in rotations of short to medium length, thinning should play a secondary role, mostly as a sanitation and salvage measure, and not be viewed as essentially a growth regulator or product developer. On the other hand, in all-purpose management that includes both small and large products, thinning will of necessity play its traditional role in the maintenance of stand vigor and diameter growth. Any decision concerning a choice between the two types of management as related to total return would involve economic considerations beyond the scope of this paper.

SUMMARY

Analysis of data on plantation yields for unthinned stands shows current annual increment to culminate from 12 to 15 years of age in all but the denser stands on site 50. Culmination occurs over a wide range of basal areas, indicating that maximum growth is most strongly influenced by the pattern of diameter and height growth as related to average tree size or diameter distribution array.

Mean annual increment (to the nearest hundredth of a cord) culminates from 25 to 27 years of age in stands of 500 trees per acre or less.

On the assumption that a thinned stand will grow at the same rate as an unthinned stand with the same number of trees per acre, thinning appears to have little effect on total cubic yield.

Primary product objective should determine initial spacing, and thinning under this condition assumes little importance as a regulator of growth in rotations of short to medium length.

In multiple-product management involving large and small roundwood, the traditional role of thinning as a regulator of stand vigor and diameter growth will hold.

[6] Bennett, Frank A. Spacing and slash pine quality timber production. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-53, 9 pp. 1969.

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Bennett, Frank A.
1971. The role of thinning and some other problems in management of slash pine plantations. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-86, 14 pp.

Detailed data on growth of unthinned slash pine (Pinus elliottii var. elliottii) plantations are presented. Through the use of these data, the possible effect of thinning is assessed, and the role of thinning in plantation management is evaluated.

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Adaptability of Geographic Selections of Shortleaf Pine to Littleleaf Sites

by
John L. Ruehle and W. A. Campbell

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U.S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

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by

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INTRODUCTION

In the piedmont plateau and upper Coastal Plain, from Virginia to Mississippi, the threat of littleleaf disease has resulted in discrimination against shortleaf pine (Pinus echinata Mill.) in reforestation programs. This disease, caused by the soil fungus Phytophthora cinnamomi Rands, is most severe on soils having poor aeration, low fertility, and periodic moisture stress. Hence it is most damaging on eroded and abandoned agricultural land, especially where the subsoils are impervious clays. There is no practical, direct, and immediate control of littleleaf disease; many severe sites are now being managed for hardwoods or conifers other than shortleaf pine. The long-term solution of returning to shortleaf management in these areas depends upon the selection and propagation of disease resistant strains of this species.

Phytophthora cinnamomi attacks the meristematic tips of fine roots. Reduction in the extent and amount of the effective root system interferes especially with the absorption of nitrogen, leading to a gradual cessation of growth and yellowing of the foliage followed by premature death. This is a slow process--some trees show top symptoms by age 20 while others on the same site may remain symptom-free for 50 years or more.

Although P. cinnamomi is found throughout the range of littleleaf, there are extensive areas in the Coastal Plain, mountains, and west of the Mississippi River where the disease does not occur. The existence of apparently healthy stands of shortleaf pine, even in situations where

P. cinnamomi was found in the soil, suggested the existence of strains or races that might be better adapted to littleleaf site conditions than the severely diseased shortleaf on those sites. Zak[1] (1955) reported that resistance to littleleaf in shortleaf pine is heritable. His studies indicated, however, that it would take many years to develop breeding orchards, secure seed of known parentage, and properly test the progeny on known littleleaf sites.

Hence, in 1952 the Forest Service gathered seed from shortleaf stands outside the range of littleleaf (representing northern and western extremities in the range of the species) and from healthy shortleaf stands within the littleleaf belt. Seedlings from these sources were planted on sites in three severe littleleaf areas in the northern, middle, and southern Piedmont. The objective was to determine how well shortleaf pine from different geographic sources performed on severe littleleaf sites in the Piedmont.[2] This Paper reports our conclusions after 16 years of observations in the field.

INSTALLATION OF FIELD PLOTS

Seed were collected by various cooperators within the natural range of the species (table 1 and fig. 1). The seedlings from nine selections from outside the range of littleleaf and the three from within the belt were nursery grown at the School of Forestry, University of Georgia, Athens, in April 1952.

Three areas in the Piedmont judged as littleleaf sites, based on condition of the existing stands, were selected as testing sites: Calhoun Experimental Forest near Union, South Carolina; Lee Experimental Forest near Buckingham Court House, Virginia; and Oconee Forest near Athens, Georgia. Each site is gently rolling with the top soil shallow or lacking in some spots and the subsoil tight and poorly drained. All trees, brush, and vines were removed prior to planting. Two blocks, each with 12 randomly arranged plots, were established on approximately 2 acres in each of the three areas. Each plot consisted of a double row of 23 trees, or a total of 46 trees. Tree spacing was 6 by 6 feet with isolation strips around each block.

The seedlings were lifted and hand planted at each location during January and February 1953. Plants lost in 1953 were replaced in January 1954 with holdover stock of the same age. Because of this replacement of initial losses, the average survival recorded in 1961 was good on all three locations: Athens = $\bar{x}$ 93%(96-88), Lee Experimental Forest = $\bar{x}$ 80%(91-70), Union = $\bar{x}$ 94%(100-90).

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[1] Zak, Bratislav. Inheritance of resistance to littleleaf in shortleaf pines. USDA Forest Serv. Southeast. Forest Exp. Stn. Res. Notes 88, 2 pp. 1955.

[2] For their contributions to the planning, planting, and maintenance of the geographic selection plots, G. H. Hepting, B. Zak, W. C. Bryan, and R. G. McAlpine are due special thanks.

Table 1.--Sources of 12 lots of shortleaf pine seed collected in 1951

Designation	Source	Latitude N.
L	Alto, Cherokee County, Texas	32°
M	Maydelle, Cherokee County, Texas	32°
I	Austin Experimental Forest, Nacogdoches County, Texas	32°
H	Nevada County, Arkansas	34°
C	Asheley County, Arkansas	33°
E	Oxford, Lafayette County, Mississippi	34°
A	Jefferson County, Alabama[1]	34°
B	Stone County, Arkansas	36°
P	Farmville, Prince Edward County, Virginia[1]	37°
O	Louisa County, Virginia[1]	38°
S	Pennsylvania[2]	40°
T	New Jersey[2]	40°

[1]Located within the Piedmont area having scattered to abundant littleleaf.
[2]Establishment report did not designate county.

Figure 1.--Location of 12 seed sources and the plantations in which they were tested.

EVALUATION AND MEASUREMENTS

During January and February 1970, all trees were measured for outside bark diameter at breast height (d.b.h.) and total height and were rated for condition. Because very few trees at this age showed symptoms of advanced stages of littleleaf, a condition rating was used instead of a disease rating. The trees were rated as follows: 5 = healthy; 4 = growth reduction evident, the crown somewhat thinner and the needles green but shorter than on healthy trees; 3 = crown definitely thin with some twig mortality, lower branches dying, foliage yellow-green, needles very short, reduced branch increment producing a tufted crown; 2 = very sick tree, twig mortality extensive, foliage tufted and yellow; 1 = dead tree, foliage brown, tree obviously just died, possibly from root disease and not injury or suppression.

A regression analysis was made on the data with a least-squares computer program. The data on each tree were included unless the tree was suppressed, had uncharacteristic twisted growth, or had been injured by ice storms or windthrow.

RESULTS

The total sums of squares were partitioned into main effects (locations, blocks, and seed source) and interactions (sources x locations and source x blocks). The test statistic F.05 was used in the analysis of variance and both interactions were statistically significant for all three parameters (diameter, height, condition). Therefore, a separate t-test $t_{(1,2576)} = \frac{\bar{S}_2 - \bar{S}_1}{\text{std. error}}$ was made for each source within each location and for location comparisons for each source.

The means for all three parameters were grouped by location, and the seed sources were arranged in order from west to east. The important variables were condition and height. Since survival was high and d.b.h. was apparently confounded with height, diameter was combined with height to give volume per acre.

A comparison of conditions (fig. 2) showed sources T (N.J.) and O (Va.) averaged best over all locations and E (Miss.), H (Ark.), and I (Tex.) averaged worst over all locations. A trend of healthier trees from southwest to northeast is indicated at all three plantations. The strongest trend is noted at Union where the site conditions were most severe. The comparison of conditions between plantations for sources from the same general geographic areas, such as three sources from Texas, three from Arkansas, and two from Virginia, showed a fairly consistent pattern for all but two cases--L (Tex.) at Lee and B (Ark.) at Union. The L (Tex.) source may have come from parents differing genetically for reasons unrelated to climate because the three Texas sources came from adjoining counties. The B (Ark.) source may have

responded atypically because of differences in climate within Arkansas; e.g., latitude of B is more similar to the Virginia collection points than to H and C in southern Arkansas.

Generally the upland sources--B (Ark.), A (Ala.), O and P (Va.), and S (Pa.)--were healthier at all three plantations than the group of sources from coastal plain sites--E (Miss.), H and C (Ark.), and I, L, and M (Tex.).

A west-to-east trend in increasing growth rate was suggested from the height data at Lee, but was not evident at the other two plantations (fig. 3). A comparison of heights among plantations for sources from the same states showed a consistent pattern for all except L (Tex.). The overall best height growth was made at Athens and the poorest at Union for all 12 seed sources. When average height was plotted over condition, only at Lee was it clear that healthy trees grew faster. At Athens there were several reversals--H (Ark.) and E (Miss.) averaged among the best in height but among the poorest in condition.

The average d.b.h. and average height for each source within each plot were used in an equation[3] to estimate volume per acre. The ranking of means of each source over all locations showed P (Va.) the highest at 1,899.7 cu. ft./acre and I (Tex.) the lowest at 1,152.7 cu. ft./acre (table 2). The trends established in the height data were unchanged after height was combined with d.b.h. to estimate volume per acre.

Table 2.--Computed volumes, at age 16, of shortleaf from 12 sources planted at three locations

Location	Seed source												Location means
	L (Tex.)	M (Tex.)	I (Tex.)	H (Ark.)	C (Ark.)	E (Miss.)	A (Ala.)	B (Ark.)	P (Va.)	O (Va.)	S (Pa.)	T (N. J.)	
	Cu. ft./acre												
Athens	1,995	2,302	1,705	2,042	2,306	2,094	2,148	1,754	2,397	2,252	1,483	1,754	2,086
Union	1,221	1,239	866	903	1,144	1,150	1,309	840	1,523	1,208	984	996	1,115
Lee	1,332	1,608	886	974	1,126	1,178	1,538	1,461	1,778	1,502	1,847	1,893	1,427
Source means	1,516	1,883	1,152	1,306	1,525	1,474	1,765	1,351	1,899	1,654	1,438	1,548	

CONCLUSIONS

These shortleaf seed sources are expected to be well differentiated into resistant or nonresistant groups after 25 years of age. After 16 years, classical littleleaf symptoms were evident in some sources. At the Union plantation, obviously the poorest site for growth and tree condition, some trees were in such a state of decline that they probably will not survive to age 25.

[3] An unpublished formula derived by Dr. Charles Webb, Athens, from a study of 10-year-old shortleaf pine--$\hat{Y} = 1.015825 + 0.026363\ X$, where X is product of d.b.h. (outside bark) in inches and total height in feet, and $\hat{Y}$ is estimated volume of individual trees.

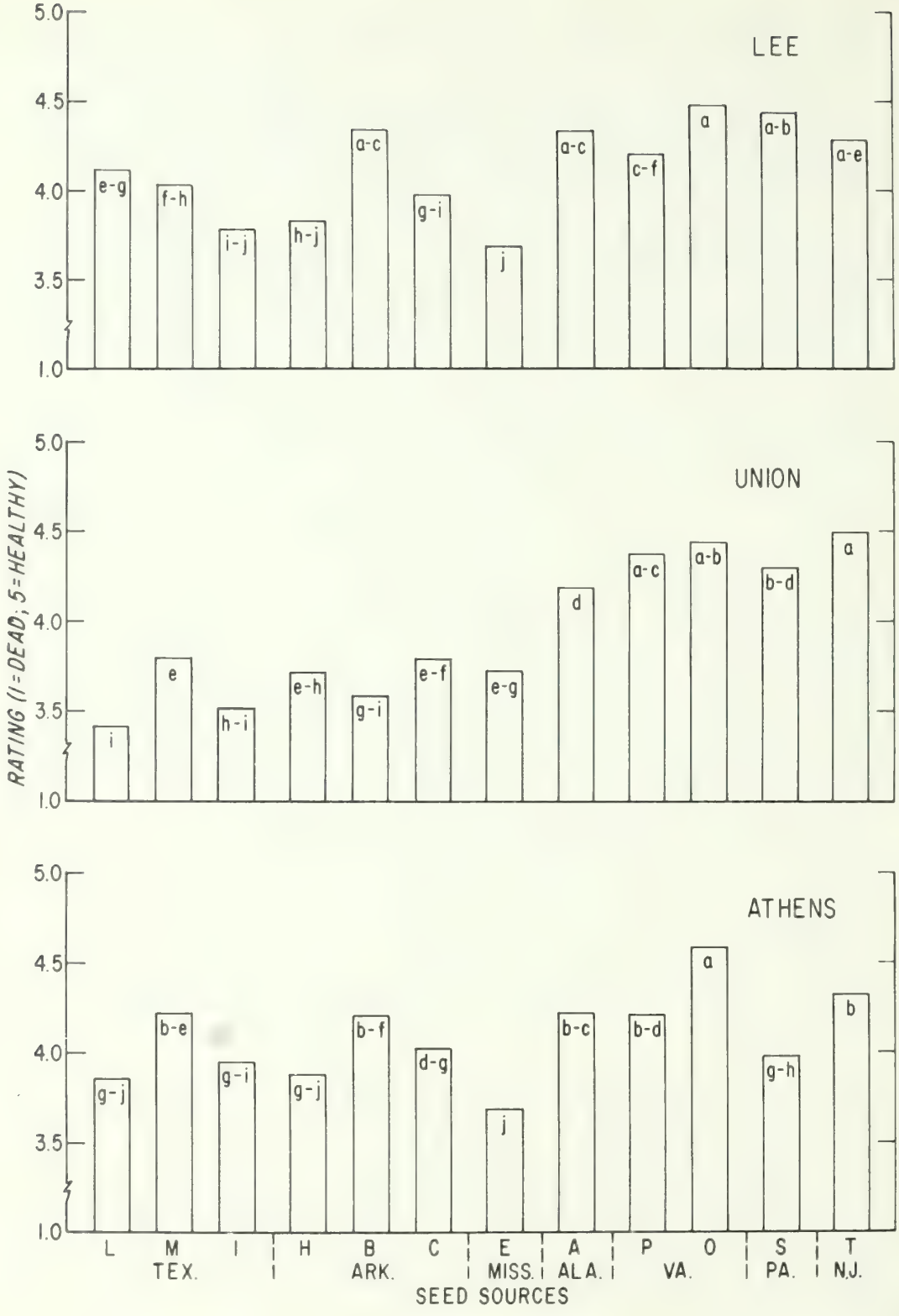

Figure 2.--Condition ratings of 12 shortleaf seed sources in three plantations within the littleleaf range. Bars with the same letters show sources not significantly different at $P \leq 0.05$.

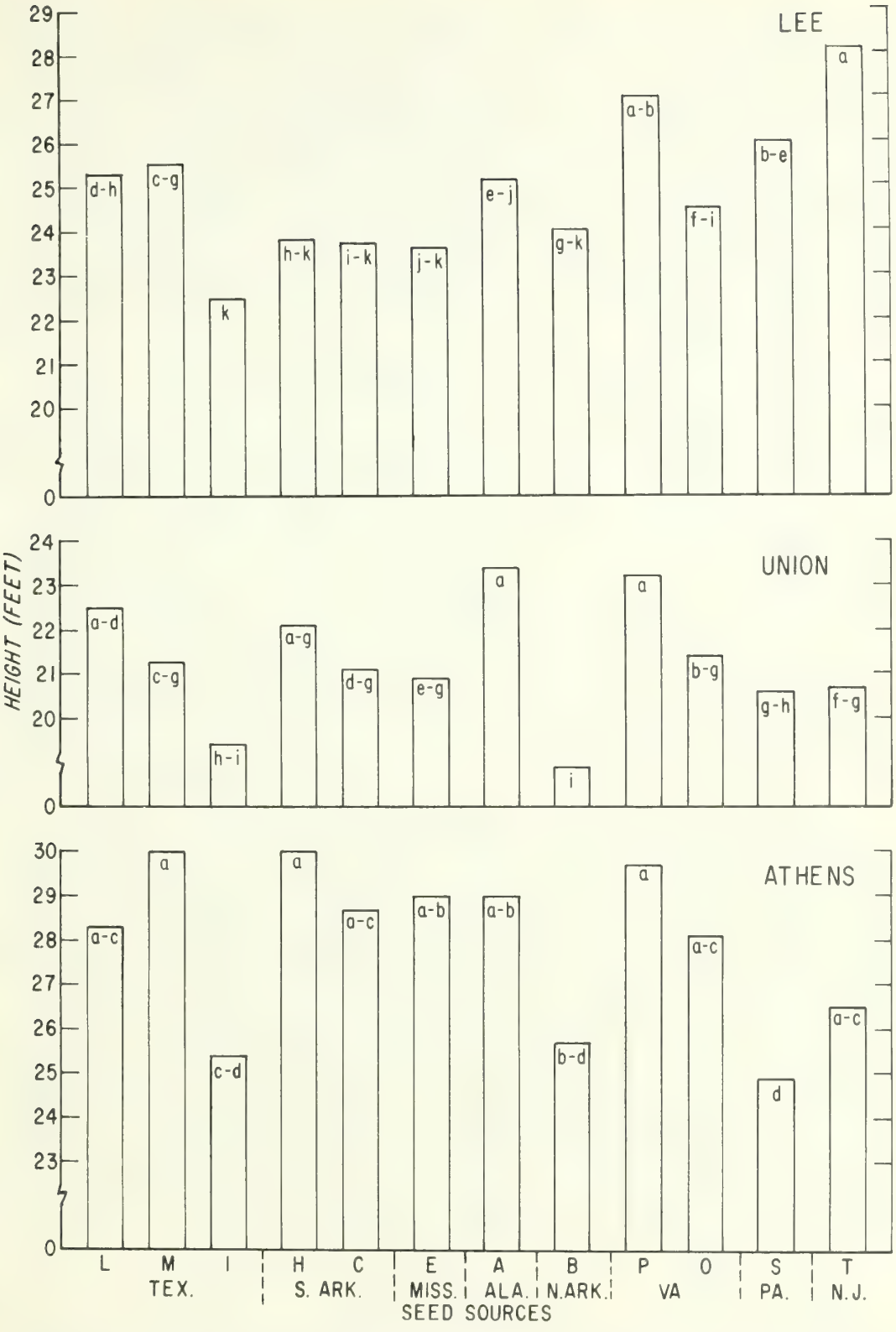

Figure 3.--Heights of 12 shortleaf seed sources in three plantations within the littleleaf range. Bars with the same letters show sources not significantly different at $P \leq 0.05$.

Variation among trees from different seed sources was evident in all three parameters, although less in d.b.h. than in height and condition. Considerable variation in condition and d.b.h. attributable to plantation location was seen within some sources--L, M, and I (Tex.)--and surprisingly little was seen in others--P (Va.), S (Pa.), and A (Ala.). Plantation location had more effect on height; almost all selections grew tallest at Athens and shortest at Union. Location effect was not related to latitude, but was mainly the result of differences in soil type and characteristics. Athens, the southernmost site, was the most fertile as indicated by its dense understory. The Lee Experimental Forest, the northernmost location, was the next best site, and Union at the middle latitude, was the least fertile site.

Consideration of all three parameters for each source over all locations ranked P (Va.) the best (condition = 1.72, height = 26.7, d.b.h. = 4.2). The P (Va.) seed, obtained from an area having abundant littleleaf, may have come from parents naturally selected for resistance to this disease. Zak[4] tested seed from such apparently resistant trees in heavily diseased stands in Georgia and found that seedlings from certain of these selections, when tested under severe disease conditions, exhibited a high degree of resistance. Therefore, seed selected from resistant trees within the range of littleleaf may perform better than seed randomly selected from trees outside the range that have not been subjected to selection pressure. Southern pines from local seed generally outperform planting stock obtained from well outside the area. Wakeley[5] found height growth and volume are particularly related to latitude; we found this to be true for shortleaf in our study. Selections from latitudes close to the latitude of the planting site generally did better in height growth than those from more distant latitudes.

Unfortunately we did not include local seed for each of the three planting sites to compare with the 12 selections collected. This omission will make it difficult to decide whether certain nonlocal seed sources are really best for use on littleleaf sites. A general conclusion may be ventured, however. There is an indication that shortleaf pine can be successfully selected for adaptability to littleleaf sites. Wakeley[6] stated that physiological and other characteristics which render certain races well adapted to one environment and poorly adapted to another are controlled more strongly by genetic constitution than by cultural or other external influences, and that disease resistance of trees in any particular locality often depends more upon tree ancestry than tree spacing or stand composition. We can certainly remain optimistic that geographic sources can be used as one means of obtaining germ plasm for selection and breeding of superior shortleaf pines for planting in the Piedmont. There is even a good possibility that trees surviving in these plots after 25 years may be used for breeding stock adaptable to littleleaf sites.

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[4] Zak, loc. cit.

[5] Wakeley, P. C. The relation of geographic race to forest tree improvement. J. Forest. 52: 635. 1954.

[6] Wakeley, P. C. Planting the southern pines. USDA Forest Serv. South. Forest Exp. Stn. Occas. Pap. 122, 579 pp. (3 vols.). 1951.

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Growth and condition of geographic sources of shortleaf pine were evaluated after 16 years on three littleleaf sites in the Piedmont. A trend of healthier trees from sources west to east was indicated at three plantations, and upland sources were healthier at all three plantations than were sources from Coastal Plain sites. Variation among trees from different seed sources was evident in height and condition. General conclusion is that shortleaf pine can be successfully selected for adaptability to littleleaf sites.

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USDA Forest Service Research Paper SE-88 October 1971

Correlations Between Reproductive and Vegetative Growth in a 6-Year-Old Virginia Pine Plantation

by
David L. Bramlett

U.S. Department of Agriculture–Forest Service
Southeastern Forest Experiment Station
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Correlations Between Reproductive and Vegetative Growth in a 6-Year-Old Virginia Pine Plantation

by

David L. Bramlett, Plant Physiologist
Blacksburg, Virginia

INTRODUCTION

Precocious flowering in forest trees offers important advantages for genetic and physiological research. Early flowering permits tree breeders to accelerate their programs by substantially reducing the generation interval. The small size of such trees facilitates controlled pollinations and cone collections. Small, experimental material is also better suited to the study of flower, cone, and seed development. For these reasons, precocious flowering in the genus Pinus has received considerable attention and has been noted in many species (Righter 1939; Mergen and Cutting 1957; Fielding 1960; Mergen 1961; Greene and Porterfield 1963; Gerhold 1966; Rudolph 1966; Heimburger and Fowler 1969; Smith and Konar 1969). This study presents quantitative data on the frequency of early flowering in a Virginia pine plantation and the relationship of reproductive and vegetative growth for the initial 6 years.

METHODS

The plantation observed in this study comprises a one-parent progeny test designed to evaluate the heritability of natural pruning in Virginia pine. Thirty parent trees were selected as 15 pairs, each pair representing a well-pruned and poorly pruned tree from the same stand. Other characteristics (diameter, height, and surrounding basal area) were similar. Seed collected in the fall of 1963 were planted in a nursery bed, and the seedlings were outplanted at 8- by 8-ft. spacing in the spring of 1965. The planting design consisted of completely random single-tree plots with 10 trees from each parent. Survival of the 300 study trees was 98.7 percent after 5 years in the field. The outplanting site is comprised of Virginia Piedmont Nason and Tatum soils with moderate slope. This area was in cultivation 30 or so years ago and was subsequently occupied by a young, open-grown stand of Virginia and shortleaf pine (Pinus echinata Mill.). Prior to the present planting, it was cleared, windrowed, and disked.

RESULTS AND DISCUSSION

The plantation means of tree height, stem diameter, and flower production for the years 1965-70 are listed in table 1.

Table 1.--Means of vegetative and reproductive measurements of the Virginia pine plantation

Year	Vegetative (December)			Reproductive (April)	
	Height	Stem diameter[1]	D.b.h.	Male catkin clusters	Female flowers
	Feet	--Inches--		--Number--	
1965	0.67	--	--	0	0
1966	1.76	--	--	0	.003
1967	3.37	0.70	--	0	.05
1968	5.57	1.27	--	([2])	4.05
1969	8.35	2.09	1.01	22.98	9.20
1970	--	--	--	149.11	22.76

[1]Measured 1.0 ft. above ground.

[2]Three study trees produced male catkins, but number of catkin clusters per tree was not recorded.

The percentage of trees with female flowers (megasporangiate strobili) was 0 at age 1, 0.3 at age 2, 4 at age 3, 66 at age 4, 81 at age 5, and 94 at age 6. The average number of female flowers per tree increased from 0.003 in 1966 to 22.8 in 1970. The plantation produced about 15,500 flowers per acre in 1970. If 75 percent survival of flowers and 25 sound seed per cone is assumed, it is reasonable to estimate that 300,000 sound seeds per acre could be produced in the fall of 1971.

Male catkins (microsporangiate strobili) were not observed on any plantation tree until 1968, when 1 percent of the trees produced pollen. By 1969 (age 5), 51 percent of the trees had male catkins, and 92 percent of the trees were producing pollen by 1970. The 1970 average of 149 catkin clusters per tree was surprising. Generally, pollen production lags considerably behind female flower initiation and may be limiting in young plantations.

Regression analysis was used in this study to relate the 5-year measurements of height and diameter with reproductive development. The simple correlation coefficients of all vegetative and reproductive variables are presented in table 2.

The additive effects of certain significant independent variables when the number of female flowers per tree in 1970 was used as the dependent variable in stepwise multiple regression are noted in table 3. In

Table 2.--Correlation matrix of variables from the Virginia pine plantation[1] [2]

	66 Ht.	67 Ht.	68 Ht.	69 Ht.	67 SD	68 SD	69 SD	69 D.b.h.	69 M	70 M	68 F	69 F	70 F
65 Ht.	0.844	0.724	0.622	0.517	0.729	0.528	0.516	0.546	0.229	0.357	0.218	0.283	0.257
66 Ht.		.867	.774	.656	.856	.695	.673	.667	.308	.458	.285	.340	.330
67 Ht.			.886	.781	.865	.775	.765	.782	.306	.493	.206	.274	.279
68 Ht.				.917	.818	.783	.816	.877	.279	.475	.214	.259	.275
69 Ht.					.727	.746	.796	.893	.224	.388	.153	.202	.209
67 SD						.848	.822	.782	.340	.510	.286	.358	.365
68 SD							.844	.790	.282	.455	.220	.313	.314
69 SD								.848	.266	.480	.207	.299	.317
69 D.b.h.									.265	.463	.181	.240	.280
69 M										.676	.250	.236	.239
70 M											.254	.245	.289
68 F												.684	.710
69 F													.661

[1] 65-69 Ht. = tree height; 67-69 SD = stem diameter at 1.0 ft. above ground; 69 D.b.h. = stem diameter at 4.5 ft. above ground; 69-70 M = number of male catkin clusters per tree; 68-70 F = number of female flowers per tree.

[2] r values greater than 0.113 are significant at 0.05 level of probability.

Table 3.--Stepwise regression analysis of vegetative and reproductive variables measured in the Virginia pine plantation

Step number	Dependent variables							
	1970 female flowers				1970 male catkin clusters			
	Independent variable added	d.f.	R^2	Regression F value	Independent variable added	d.f.	R^2	Regression F value
1	1968 female flowers	1/294	0.504	298.18**	1969 male catkins	1/294	0.457	247.54**
2	1969 female flowers	2/293	.561	187.4 **	1969 stem diameter	2/293	.554	182.5 **
3	1969 stem diameter	3/292	.576	132.5 **	1967 height	3/292	.565	126.2 **

** Significant at 0.01 level of probability.

the regression analysis, previous flower production in 1968 and 1969 were the most important variables, and together they had an R^2 value of 0.561. The 1969 stem diameter entered third, bringing the R^2 value to 0.576.

With the 1970 male catkin as the dependent variable, the 1969 male catkin production was the strongest independent variable, followed by 1969 stem diameter and 1967 height (table 3). Again, previous reproductive growth was more important than vegetative growth: 1969 male catkins had an R^2 value of 0.457 and the two vegetative variables--1969 stem diameter and 1967 height--increased the R^2 value by only 0.108.

The relative importance of past reproductive performance on the production of male and female flowers (table 2) indicates some inherent control of flowering. Analysis of variance of the 30 half-sib families for

all variables indicated significant differences for all variables measured except the 1969 female flowers. The differences between families were used to compute the heritability of reproductive traits by the equation

$$h^2 = \frac{4\ \sigma_F^2}{\sigma_F^2 + \sigma_W^2} \quad \text{(Becker 1967, p. 9)}$$

where σ_F^2 = mean square between families minus mean square within families divided by number of progeny per family, and

σ_W^2 = mean square within families.

Heritability estimates for female flowering were 0.59 in 1968 and 0.65 in 1970. For male flowering, the heritability estimates were 0.48 in 1969 and 0.44 in 1970. These heritabilities indicate a large amount of additive genetic variation in reproductive development at early ages. In contrast, Varnell et al. (1967) estimated heritability of fruitfulness in slash pine (Pinus elliottii Engelm.) at 0.13. The nonsignificant family difference in female flower production in 1969 is unexplained, but it may reflect a relatively large difference among families to some environmental effect during the period of flower initiation in 1968.

The age at which the trees first began producing flowers was a strong factor in the flower production for 1970. Mean flower production in 1970 was 42 for trees that began producing flowers at age 3, 29 for those that began at age 4, 11 for those that began at age 5, and 8 for those that began at age 6. Some exceptions to this trend occurred when trees decreased in production from one year to the next, but the general pattern was that the trees that flowered most precociously were also the most prolific.

As considerable energy is required for reproductive development (Fielding 1960), it is possible that heavy flowering could cause a reduction in vegetative growth. In this study, flowering trees were significantly taller than nonproducers in 3 of the 4 years of flower production (table 4). When the trees were stratified into six height

Table 4.--Height growth of flowering and nonflowering trees in the Virginia pine plantation

Year	Mean height		F ratio	Level of significance
	Flowering	Nonflowering		
	- - -Feet - - -			
1966-67	2.05	1.75	4.80	0.01
1967-68	3.45	3.21	7.12	.01
1968-69	5.63	5.19	7.07	.01
1969-70	8.35	8.26	.04	NS

classes, the tallest trees at age 6 had more male and more female flowers (table 5). This finding agrees with that of Schmidtling (1969). Thus, it appears that taller trees have more flowers and that, up to age 6, flower production does not seriously reduce height growth. The more subtle question of the vegetative height growth of the tallest trees without any male or female flowers remains unanswered.

Table 5.--Mean number of male and female flowers in 1970 for six height classes in the Virginia pine plantation

Height class (feet)	Trees	Plantation mean	
		Female flowers	Male catkin clusters
	- - - - - - - - Number - - - - - - - -		
10.1 and larger	25	34.4	266.6
9.1-10.0	59	24.5	196.4
8.1- 9.0	89	23.7	167.0
7.1- 8.0	88	22.3	97.5
6.1- 7.0	25	11.1	62.3
6.0 or less	10	8.0	88.9

From the observations in this Virginia pine plantation, it is evident that insufficient production of either male or female strobili is not a factor hindering early selection of second-generation progeny for further crossing and seed production. The major problem now must be the reliability of juvenile-adult correlation of desired characteristics. This correlation can only come with time as present-day stands continue to grow. It seems reasonable, however, to make selections now when the progeny reach the age of adequate seed production--at 5 or 6 years. Parents can be retained and remeasured. If the correlations hold reasonably well, a breeding cycle of 5 years should allow for rapid genetic gain.

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Bramlett, David L.
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Ninety-four percent of the trees in a Virginia pine (Pinus virginiana Mill.) plantation produced female flowers at 6 years of age, and 92 percent of the trees produced male flowers. The average number of female flowers per tree was 23; the average number of male catkin clusters was 149. Flower production at age 6 was much more closely related to past flower production than to height or diameter growth. Heritability estimates of female flower production from the half-sib families were 0.59 and 0.65 for the years 1968 and 1970. Estimates of male flowering heritability were 0.48 and 0.44 for 1969 and 1970. Flower production did not appear to be detrimental to juvenile height growth, as the flowering trees were significantly taller during 3 of the 4 years of flower production.

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Early Growth and Development of Slash Pine Under Drought and Flooding

by

James W. McMinn
and
W. Henry McNab

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Early Growth and Development of Slash Pine Under Drought and Flooding[1]

by

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Athens, Georgia

and

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INTRODUCTION

The semitropical pattern of precipitation in south Florida poses a difficult problem for direct seeding of pine. Monthly rainfall during December, January, and February averages less than 2 inches. It is not unusual to go without measurable precipitation during any one of these months. Moreover, rains during this period usually are of less than half an inch and are ineffective in replenishing soil moisture.

In contrast, June, July, August, and September average 8 inches or more per month. An occasional 15 inches fall during a single month, and in a single rain 4 inches or more are common. During summer and early autumn, water usually stands above the soil surface over south Florida's wet prairies and much of the pine flatwoods. Rainfall decreases sharply in October. November precipitation is usually as low as that of the following winter months, but soil moisture during the autumn is often ample to excessive, depending on the amount of rain during the preceding months.

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[1] The authors were formerly stationed at Fort Myers, Florida. The study was presented in a thesis by McNab to the Graduate Council of the University of Florida in partial fulfillment of the requirements for the degree of Master of Science in Forestry (McNab, W. Henry. Response to drought and flooding of two varieties of slash pine in south Florida. Unpublished Master's thesis, Univ. Fla. 1965).

Extreme moisture conditions are adverse to the growth and development of pine seedlings and, therefore, are problems to be resolved if direct seeding is to be successful in south Florida. Establishing slash pine by direct seeding may be the most economical way to reforest millions of acres of cutover pineland in this area when there are insufficient seed trees for natural regeneration. The influence of seeding depth and season on germination and survival has been presented in an earlier paper.[2] However, techniques that will insure consistent establishment of seedlings must be developed. Determination of tolerance to drought and flooding of newly established pine seedlings in south Florida is essential for development of reliable seeding techniques.

The objective of this study was to determine the growth and development of typical slash pine (Pinus elliottii var. elliottii) and South Florida slash pine (Pinus elliottii var. densa Little & Dorman) seedlings under varying levels of winter drought and summer flooding. The study was conducted in Charlotte County, Florida, on the Caloosa Experimental Range, in cooperation with the Babcock Florida Company and the Florida Division of Forestry.

METHODS

Oil drums (55-gallon) were steam-cleaned and cut in half to form open-top cans 17 inches tall. Twenty-seven cans were arranged in two groups, by pairs, with the long axes extending north and south (fig. 1). The study was divided into three blocks of nine cans each. Each can constituted a whole plot, and the two varieties of slash pine planted in each can constituted two subplots. A wooden wall was built around each group to retain sawdust packed between the drums for insulation.

Four inches of gravel were placed in the bottom of each can. The cans were then filled with Adamsville fine sand surface soil. After being watered-down, the soil was about 11 inches deep and its surface was about 2 inches below the top of each can. Water level was controlled by inserting a stoppered drain hose near the bottom of each can. The installation was sheltered from precipitation by arches of steel pipe covered with clear plastic. Practically no shadow was cast by this structure, and there was free circulation of air.

The soil-filled cans were treated with methyl bromide to eliminate weed growth. Surface litter from pine flatwoods was spread on top of the soil, and seed were evenly sown in mid-December 1963. No attempt was made to plant the seeds, but they were watered frequently to ensure good germination. The seeds germinated promptly, and seedlings were thinned to 30 in each subplot.

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[2] McMinn, James W. Optimum depth and season for direct seeding slash pine in south Florida. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-73, 7 pp. 1970.

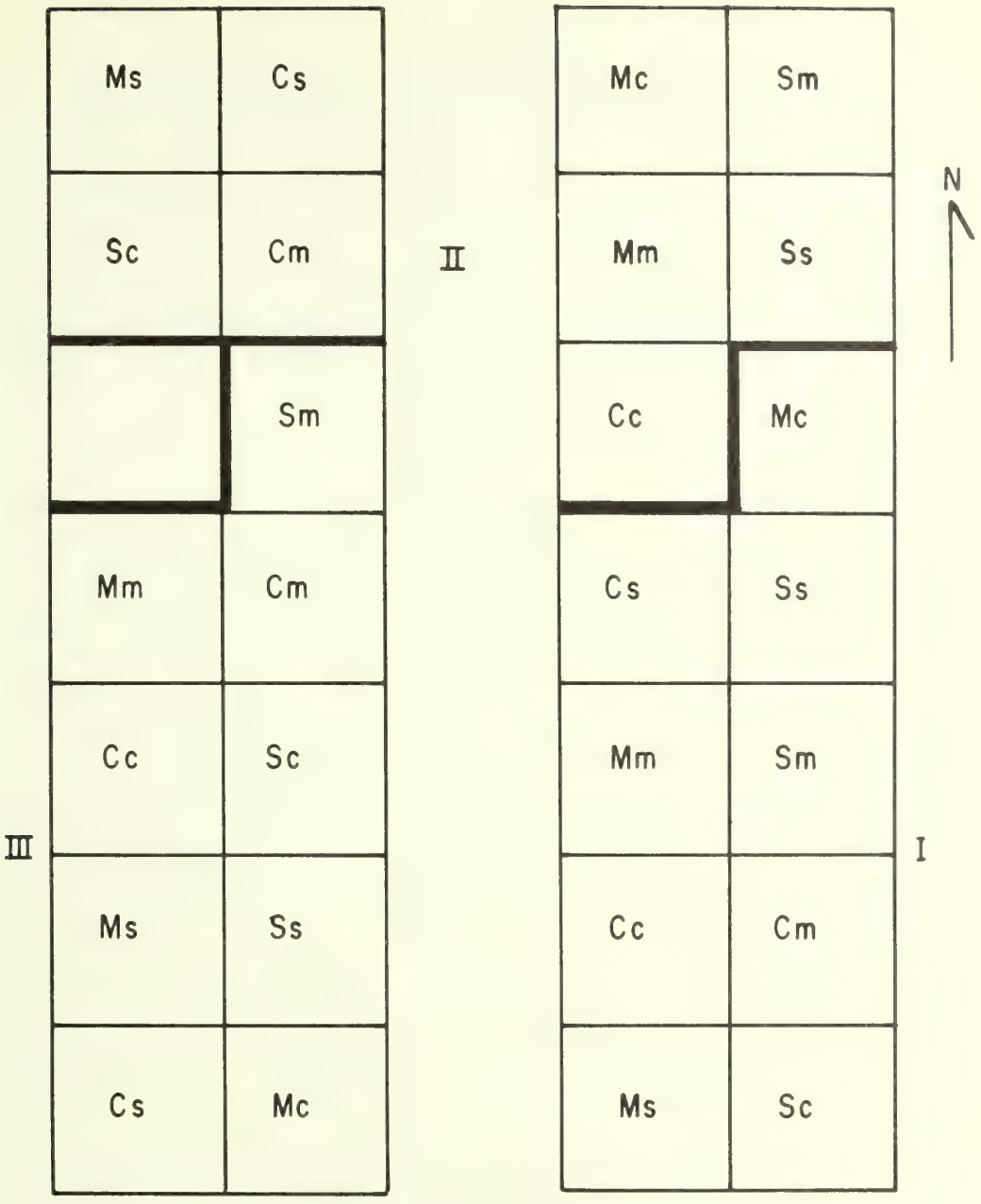

Figure 1.--Arrangement of blocks and whole-plots (cans). Roman numerals designate blocks, uppercase letters denote drought treatments (control, mild, severe), and lowercase letters denote subsequent flooding treatments.

Drought treatments were begun on January 9, 1964, and continued through the following May. Flooding treatments were started in June and terminated the last week of August 1964. Three levels of drought were followed by three levels of flooding. The nine combinations were randomly assigned to the nine whole-plots (cans) within each block.

Levels of drought treatment were:

Control--An approximation of field capacity. Soil moisture was held between 12 and 20 percent and averaged 16 percent.

Mild drought--No water applied until April 1, when the mean moisture level of the soil at 2 inches was 5 percent. Soil moisture was then held between 5 and 10 percent.

Severe drought--Gradual depletion approximately to the wilting point. These plots were not watered until June 1, just before initiation of the flooding phase, when watering was necessary to prevent excessive mortality. At that time the mean moisture level was 4 percent.

The estimate of field capacity was obtained from measurements made directly on the soil in the cans. Wilting point was estimated from laboratory determinations on similar soils from southern Florida. Levels of drought treatment were checked by gravimetric samples in the surface 3 inches of soil. Moisture fluctuation and sampling error were large. The 5-percent confidence intervals of the mild and severe treatments overlapped throughout the drought phase of the study.

Levels of flooding treatment were:

Control--Water level maintained 12 inches below the soil surface.

Mild flooding--Water level maintained for consecutive 2-week intervals at the following depths from the soil surface: 12 inches below, 6 inches below, 1 inch above, and 6 inches below. At the end of the 8 weeks, the cycle was repeated.

Severe flooding--Water level maintained at least 1 inch above the soil surface.

During the flooding phase, water levels were checked at 2-day intervals in 1/2-inch plastic pipe wells which were installed in the center of each can.

Seedling traits were observed at the end of the drought phase in mid-May and at the end of the flooding phase in August 1964. The following aboveground observations were made:

1. Seedling height from the ground line to the tip of the terminal bud
2. Seedling weight
3. Live crown (height and weight)
4. Stem below the live crown (height and weight)
5. Needle number, length, and dry weight.

Below-ground observations were as follows:

1. Taproot length
2. Number of primary and secondary roots
3. Mycorrhizae (number)
4. Weight of root system.

Five seedlings from each subplot were excavated and observed; all subplots were large enough for the initial five to be excavated at the termination of the drought phase with an ample number of undisturbed residuals for subsequent flooding. Data referred to in the following sections are from the August 1964 observations and were subjected to an analysis of variance appropriate to the study design.

RESULTS

Shoot Development

Height of variety elliottii decreased with increasing drought severity (table 1). Average height of this variety under severe drought was only 77 percent of that under the control. Only the most severe drought treatment reduced the height of variety densa, and then only 10 percent below the control.

Both mild and severe flooding retarded height growth of variety elliottii; severe flooding had a less drastic effect than severe drought. Variety densa was unaffected by flooding.

Aboveground weight of both varieties was highest under mild drought and lowest under severe drought (table 2).

Table 1.--Height of elliottii and densa varieties in response to drought and flooding[1]

Treatment and level	Variety			
	elliottii		densa	
	Cm.	Percent of control	Cm.	Percent of control
Drought				
Control	14.3	100	7.3	100
Mild	13.0	91	7.5	103
Severe	11.0	77	6.6	90
Flooding				
Control	13.8	100	7.0	100
Mild	12.3	89	7.3	104
Severe	12.2	88	7.0	100

[1]Both variety x drought and variety x flooding interactions significant at the 0.01 level.

Table 2.--Aboveground weight of elliottii and densa varieties in response to drought and flooding[1]

Treatment and level	Variety			
	elliottii		densa	
	Grams	Percent of control	Grams	Percent of control
Drought				
Control	0.54	100	0.88	100
Mild	.67	124	.99	112
Severe	.40	74	.62	70
Flooding				
Control	.52	100	.83	100
Mild	.49	94	.85	102
Severe	.56	108	.81	98

[1]Drought response significant at the 0.01 level; flooding response nonsignificant.

Needle Development

None of the observed needle characteristics of the two varieties were affected by flooding. Number of needles per seedling was greatest under mild drought and least under severe drought (table 3). Seedlings from the severe drought treatment had about 10 percent fewer needles than did control seedlings.

Table 3.--Needle characteristics of elliottii and densa varieties in response to drought level

Variety and drought level	Needle count[1]		Needle length[2]		Needle dry weight[2]	
	Number	Percent of control	Mm.	Percent of control	Mg.	Percent of control
elliottii						
Control	101	100	40	100	4.0	100
Mild	120	119	45	112	4.6	115
Severe	91	90	36	90	3.4	85
densa						
Control	71	100	115	100	14.0	100
Mild	82	115	112	97	13.4	96
Severe	65	92	79	69	8.6	61

[1] Drought response significant at the 0.05 level.
[2] Variety x drought response significant at the 0.01 level.

In comparison with the controls, the needles of variety elliottii were about 10 percent longer under mild drought and 10 percent shorter under severe drought. Needle length of densa was about the same in the controls and under mild drought, but it decreased by approximately 30 percent under severe drought. Needle dry weight of both varieties was more sensitive in response to drought treatment, but results followed a pattern similar to that for needle length.

Development of Root System

Weight of the root systems of both varieties decreased with increasing drought (table 4). The difference between mild and severe levels was about 30 percent for variety elliottii and about 40 percent for densa. Severe flooding had a similar effect on root weight of densa, but the effect of flooding on root weight of elliottii was negligible.

Variety densa responded to both mild and severe drought with about a 40 percent increase in taproot length (table 5). Flooding had no significant effect on the development of taproots in either variety, and drought had little effect on the taproot length of elliottii.

Table 4.--Weight of the root systems of elliottii and densa varieties in response to drought and flooding[1]

Treatment and level	Variety			
	elliottii		densa	
	Mg.	Percent of control	Mg.	Percent of control
Drought				
Control	257	100	203	100
Mild	233	91	180	89
Severe	173	67	117	58
Flooding				
Control	227	100	207	100
Mild	213	94	163	79
Severe	223	98	130	63

[1]Drought response significant at the 0.01 level; variety x flooding response significant at the 0.05 level.

Table 5.--Taproot length of elliottii and densa varieties in response to drought and flooding[1]

Treatment and level	Variety			
	elliottii		densa	
	Mm.	Percent of control	Mm.	Percent of control
Drought				
Control	197	100	140	100
Mild	208	106	193	138
Severe	192	97	197	141
Flooding				
Control	195	100	184	100
Mild	200	103	184	100
Severe	203	104	162	88

[1]Variety x drought response significant at the 0.05 level; variety x flooding response nonsignificant.

Number of mycorrhizae and secondary roots per seedling were the only traits observed with a significant response to flooding but not to drought (table 6). Mycorrhizal count decreased with increased flooding

to a low of around 30 percent of the control under severe flooding. Production of secondary roots showed no difference between the control and mild flooding treatments for either variety, but both varieties dropped off sharply under severe flooding. There was no significant difference in production of primary roots for any treatment.

Table 6.--Number of mycorrhizae and secondary roots per seedling on densa and elliottii varieties in response to drought and flooding[1]

Treatment and level	Variety			
	elliottii		densa	
	Number	Percent of control	Number	Percent of control
MYCORRHIZAE				
Drought				
Control	51	100	38	100
Mild	52	102	34	89
Severe	36	71	23	61
Flooding				
Control	76	100	53	100
Mild	42	55	26	49
Severe	22	29	16	30
SECONDARY ROOTS				
Drought				
Control	3.6	100	2.8	100
Mild	3.0	83	1.7	61
Severe	3.0	83	1.4	50
Flooding				
Control	3.8	100	2.2	100
Mild	3.7	97	2.2	100
Severe	2.2	58	1.5	68

[1] Mycorrhizal response to flooding significant at the 0.01 level; response of secondary roots significant at the 0.05 level. Neither trait responded significantly to drought.

Ratio of root-shoot weights was not significantly affected by flooding or drought. Root-shoot ratio averaged over the entire study was 0.428 for variety elliottii and 0.218 for densa.

Varietal Differences

A significant difference between varieties occurred for nearly every characteristic observed. Following is a varietal comparison based on the observations of all seedlings excavated at the termination of the study:

Characteristic	elliottii	densa
Height (mm.)**	128	71
Aboveground weight (grams)**	0.54	0.83
Needles per seedling**	104	73
Needle length (mm.)**	40	102
Needle dry weight (mg.)**	4	12
Weight of root system (mg.)**	221	167
Taproot length (mm.)**	199	193
Longest lateral (mm.)*	162	145
Second longest lateral (mm.)*	117	105
Number of mycorrhizae*	47	32
Number of primary roots	15.0	9.6
Number of secondary roots**	3.2	2.0
Root-shoot weight ratio**	0.428	0.218

*Significant at the 0.05 level.
**Significant at the 0.01 level.

DISCUSSION AND CONCLUSIONS

Both varieties generally exhibited a more drastic response to drought than to subsequent flooding (and flooding responses were similar regardless of the drought treatment to which the seedlings had been subjected). Drought influenced height, top weight, needle number, needle length, needle weight, and weight of the root system of variety elliottii. In variety densa, the same characteristics plus taproot length were affected by drought. Flooding had a significant effect only on top length of variety elliottii, root system weight of densa, and the number of mycorrhizae and secondary roots of both varieties.

Two responses of variety densa to drought, the development of a longer taproot and a marked decrease in needle size, suggest that this variety may have evolved under more variable conditions of soil moisture than did elliottii. However, these morphological modifications alone would not necessarily mean that densa could survive and grow better than elliottii under extreme drought. Even the reduced top weights of densa were half again as heavy as those of elliottii, and the longer taproots of densa (under drought as contrasted with the control) were the same length as elliottii taproots. Therefore, only accompanying physiological modifications (which were not determined) would give variety densa an advantage over elliottii under extreme drought.

The results of this study amplify those of previous studies of slash pine. The marked decrease in production of secondary roots and mycorrhizal occurrence with flooding offers at least a tentative explanation for the positive growth response of slash pine on ridged flatwoods sites.[3] Also, the varietal differences substantiate earlier reports of the magnitude of genetic variation within Pinus elliottii.[4 5 6]

These findings indicate that the winter-spring drought period in south Florida is more limiting to the growth and early development of slash pine seedlings than is the subsequent wet period during the summer. Therefore, in developing and applying guides for direct seeding, research and management should focus attention on this critical period.

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McMinn, James W., and McNab, W. Henry
1971. Early growth and development of slash pine under drought and flooding. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-89, 10 pp.

Development of typical slash pine (Pinus elliottii var. elliottii) and South Florida slash pine (Pinus elliottii var. densa Little & Dorman) was studied under conditions simulating south Florida's winter-spring droughts and summer floods. One of three degrees of flooding was imposed on seedlings which had been subjected to one of three degrees of drought. Results indicate that the drought period is more limiting to development of slash pine seedlings than is the subsequent wet period.

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USDA Forest Service Research Paper SE-90 December 1971

Performance in the Southern Appalachians of Eastern White Pine Seedlings from Different Provenances

by

Earl R. Sluder

and

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A range-wide provenance study of eastern white pine (Pinus strobus L.) was initiated in 1955 by the USDA Forest Service. The objectives are to study genetic variation of white pine over its range and to establish guidelines for movement of white pine seed from one area to another for forestry purposes. The Northeastern, North Central, and Southeastern Forest Experiment Stations, USDA Forest Service, and the Ontario Department of Lands and Forests, Canada, are participating in the study.

Early results from a number of plantations of the provenance study have been published. In Southern Appalachian plantations, heights at 3 years varied significantly among trees from different provenances and average height decreased with increasing latitude of the provenance (Sluder 1963). These results indicated that survival varied significantly among sources but was not correlated with latitude. When planted in the Lake States, white pine from the Southern Appalachians grew faster than those from other provenances until injured by frost (King and Nienstaedt 1969). The most recent data from several planting areas indicate that early trends in height growth were largely maintained, as indicated by correlations among measurements taken in early and later years (Wright 1970). Other results of this study have been published by Santamour (1960), Wright, Lemmien, and Bright (1963), Fowler and Dwight (1964), Funk (1965), and Fowler and Heimburger (1969).

This is a report of the performance of trees through their 10th year in three Southern Appalachian plantations established in 1959 by the Southeastern Forest Experiment Station.

METHODS

Seeds for the study were collected from natural white pine stands. Each stand was sampled by collecting cones from 10 trees distributed within a specified area. Sixteen provenances were used in the Southern Appalachian plantations (table 1, fig. 1).

Three study plantations were established: one each in Virginia, North Carolina, and Georgia. All three contained seedlings from a common set of six provenances. An additional 10 provenances were included in the North Carolina plantation (table 1). Seedlings were planted in plots in a randomized block design with four replications. Each plot contained 81 seedlings spaced 7 by 7 feet.

Table 1.--Geographic seed sources of white pine included in the Southern Appalachian plantations

Number[1]	State or province	County or township	Latitude
			Degrees N.
1	Georgia[2]	Union	34.8
2	North Carolina	Transylvania	35.2
3	Tennessee	Green	36.0
5	West Virginia[2]	Greenbriar	38.0
6	Pennsylvania[2]	Monroe	41.1
12	New York	Franklin	44.4
14	Maine	Penobscot	44.9
15	Iowa	Allamakee	43.5
16	Ohio	Ashland	40.8
18	Wisconsin	Forest	45.9
19	Minnesota[2]	Cass	47.4
20	Nova Scotia[2]	Lunenburg	44.4
23	Quebec	Pontiac	47.5
25	Ontario[2]	Spragge	46.2
30	Virginia	Pulaski	37.1
32	Michigan	Newaygo	43.5

[1]Seedlot number assigned by the Northeastern Forest Experiment Station.
[2]Seed sources planted in Georgia and Virginia. All 16 sources were planted in North Carolina.

The plantations were established in spring 1959. Site preparation consisted of plowing in Virginia and North Carolina and bulldozing or spraying of brush and greenbriars with herbicide in Georgia. The seedlings, grown in the State nursery at Morganton, North Carolina, were planted as 2-0 stock. Extra seedlings were heeled-in and used as 2-1 stock to replace those that died the first year. Fail-spots in plots of the West Virginia source in Georgia and Virginia were left vacant because there were not enough extra seedlings from that source to replace all the dead ones.

All planted seedlings were scored for survival. The center 25 in each plot were measured at ages 3, 5, and 10 years; those in the North Carolina plantation were also measured at 8 years.

Figure 1.--Geographic locations at which white pine seed was obtained for a range-wide study of racial variation. The locations of test plantations in the Southern Appalachians are indicated by triangles.

RESULTS

Survival

Survival differed significantly among seedlings from the various provenances (Sluder 1963). Average survival at 10 years (including replants) also differed significantly (5-percent level) among seedlings from these provenances in all plantations (table 2). However, at neither age was survival correlated with latitude of the provenance, average root-shoot ratio of seedling weights, or average diameter of the root collars of the seedlings.

Table 2.--Tenth-year survival (including replants) at three plantations for white pine from various provenances

North Carolina		Virginia		Georgia	
Provenance	Average survival	Provenance	Average survival	Provenance	Average survival
	Percent[1]		Percent[1]		Percent[1]
Georgia	98.0	Georgia	93.7	Georgia	93.8
Minnesota	96.2	Minnesota	93.5	Nova Scotia	91.0
North Carolina	95.5	Nova Scotia	93.2	Minnesota	85.2
Virginia	95.2	Ontario	88.9	Ontario	84.6
Ohio	95.0	Pennsylvania	80.3	Pennsylvania	77.0
Pennsylvania	94.9	West Virginia	56.6	West Virginia	33.4
Ontario	92.5				
Wisconsin	92.3				
Maine	92.3				
Michigan	92.3				
West Virginia	91.6				
Quebec	90.9				
Tennessee	89.9				
Iowa	89.7				
Nova Scotia	88.1				
New York	81.9				
Average	92.3		84.4		77.5
	[2]93.6				

[1] Means not joined by a common bracket are significantly different at the 5-percent level by Duncan's New Multiple Range Test.

[2] Average survival for the six provenances common to all plantations.

West Virginia seedlings had prominent taproots with few fibrous laterals for water absorption. This lack of laterals probably accounts for their poor survival after transplanting on the relatively severe planting sites in Georgia and Virginia.

Height

At 3 years of age, average heights of all seedlings including replants showed only minor differences from averages excluding replants; therefore, the replants were included in all analyses of height data.

Average heights of the plantations at 10 years reflected differences in site quality. In North Carolina, the average heights of the seedlings from the six provenances common to all three plantations were significantly greater than the average heights of those in the other two plantations (table 3).

Table 3.--Tenth-year heights (including replants) at three plantations for white pine from various provenances

North Carolina		Georgia		Virginia	
Provenance	Average height	Provenance	Average height	Provenance	Average height
	Feet[1]		Feet[1]		Feet[1]
Georgia	22.4	Georgia	17.8	Georgia	15.6
North Carolina	21.2	West Virginia	13.8	West Virginia	15.3
Tennessee	20.6	Pennsylvania	13.7	Pennsylvania	15.1
Pennsylvania	18.6	Nova Scotia	13.0	Nova Scotia	14.1
Michigan	[2]18.6	Ontario	11.0	Minnesota	10.1
West Virginia	17.4	Minnesota	10.4	Ontario	10.0
Ohio	17.2				
Wisconsin	16.5				
Virginia	16.0				
Nova Scotia	14.0				
Ontario	12.8				
New York	12.8				
Iowa	12.8				
Quebec	12.3				
Minnesota	11.9				
Maine	11.7				
Average	16.05		13.28		13.37
	[3]16.18				

[1] Means not joined by a common bracket are significantly different at the 5-percent level by Duncan's New Multiple Range Test.

[2] Estimated height at 10 years. These seedlings were planted 1 year later than those from the other provenances.

[3] Average height for the six provenances common to all plantations.

Average heights of trees of different provenances differed significantly in all three plantations (table 3). However, relationships among the six common sources were not the same in all plantations, as shown by a significant seed source x location interaction in a combined analysis. Ranking of the six common sources was essentially the same in the three plantations, but significant differences among the six provenances changed from plantation to plantation (table 3).

In all three outplantings, average heights of the seedlings from the various provenances at 10 years were strongly correlated with latitudes of the provenances, with slowest growth occurring in seedlings from northern sources (fig. 2). Furthermore, the slope of regression lines of average height on latitude increased with tree age. For example, the regression coefficient increased from -0.09 at age 3 to -0.68 at age 10 in North Carolina. Average heights were not correlated with elevation or longitude of seed origins.

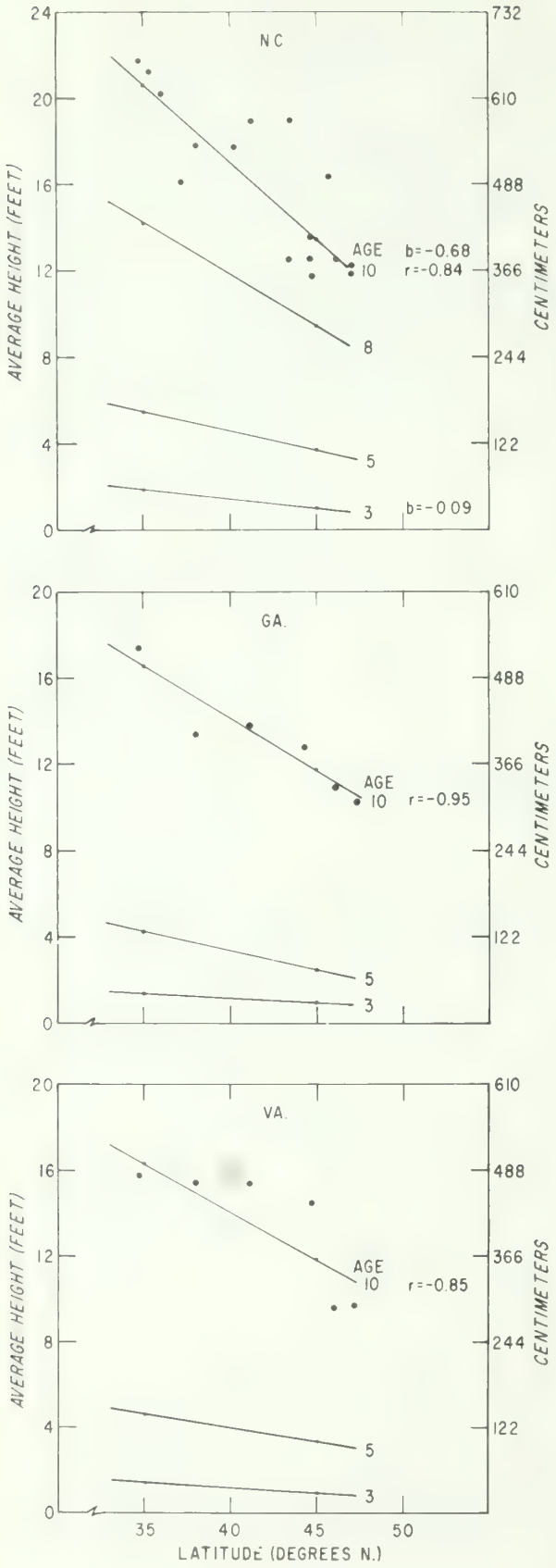

Figure 2.--Regression lines of average height of white pine from the various provenances on latitudes of the provenances for different ages of trees, all plantations.

Height-over-age curves are useful in the early stages of provenance studies to show trends in growth rate. In this study, differences in height growth were apparent at 3 years in the field and have continued through 10 years (fig. 3). These differences are widening the gap between the fast- and slow-growing seedlots. The curves of height-over-age are similar for all three plantations.

Because height variation was striking in some plots in the North Carolina plantation, within-plot coefficients of variation were calculated for all three plantations. Differences in average coefficient of variation in height were highly significant among trees from various provenances in the North Carolina plantation:

Provenance	Average coefficient of variation[1] (Percent)
Quebec	34.44
Ontario	32.95
Maine	32.11
New York	28.99
Iowa	28.74
Minnesota	28.26
Nova Scotia	28.01
Wisconsin	26.42
Virginia	22.07
Michigan	22.00
West Virginia	20.86
Georgia	19.03
Tennessee	18.92
Pennsylvania	18.61
North Carolina	15.12
Ohio	14.94
Average	24.47

However, there were no significant differences in the Georgia and Virginia plantations. Differences in the North Carolina plantation were highly significant both when data from all 16 provenances were analyzed and when data from only the six provenances common to all three plantations were considered.

Average coefficient of within-plot variation in the North Carolina plantation was highly correlated with latitudes of the provenances (fig. 4). Individual trees in plots of northern origin were more variable in height than were those in plots of southern origin. Latitude of seed source accounted for 62 percent of the variation among average coefficients of variation ($r = 0.79$).

[1]Means not joined by a common bracket are significantly different at the 5-percent level by Duncan's New Multiple Range Test.

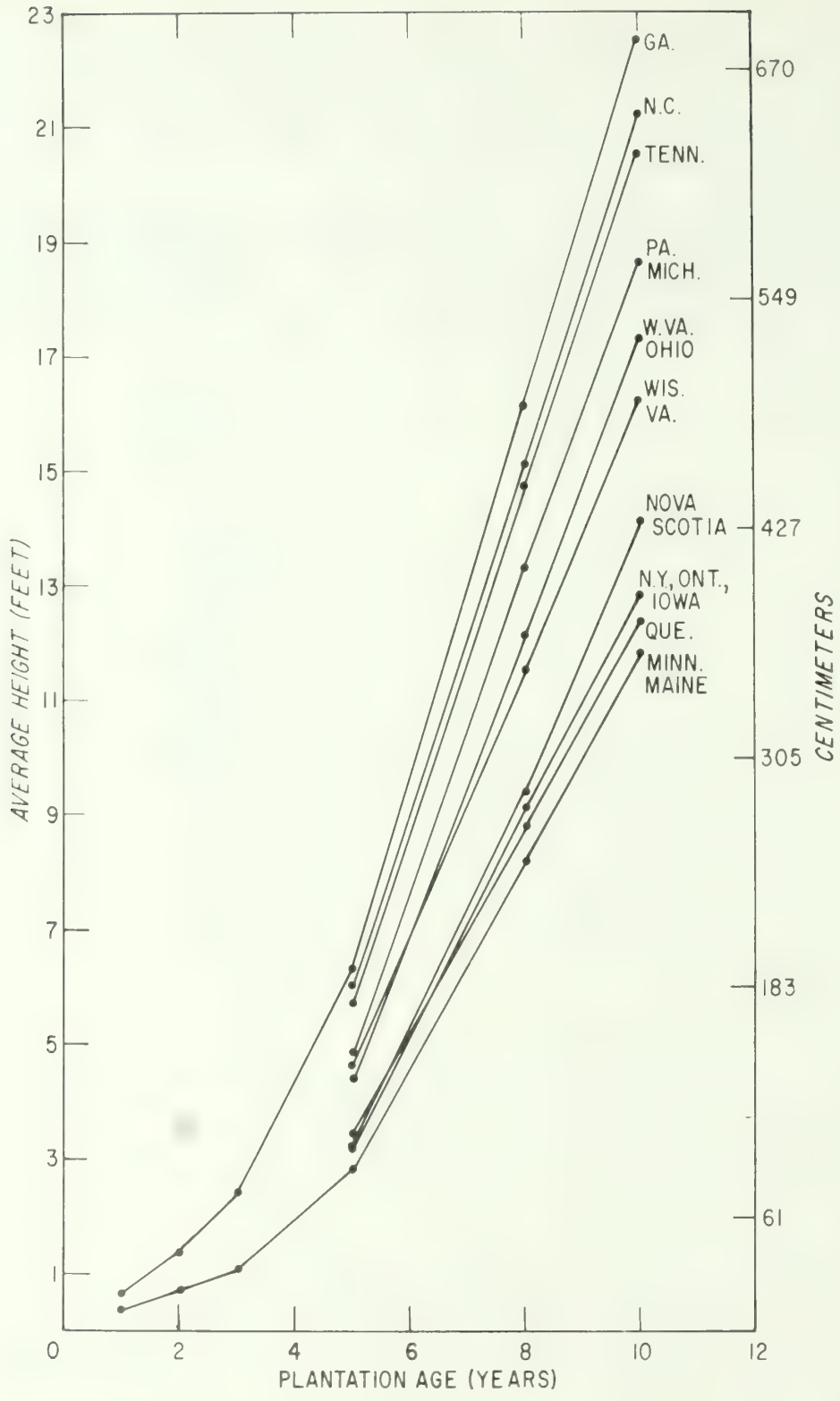

Figure 3.--Height-age relationships in the North Carolina plantation for white pine from various provenances. Growth data for the first 5-year period were given in Sluder (1963). Curves for trees from only the tallest and shortest sources are shown for that period.

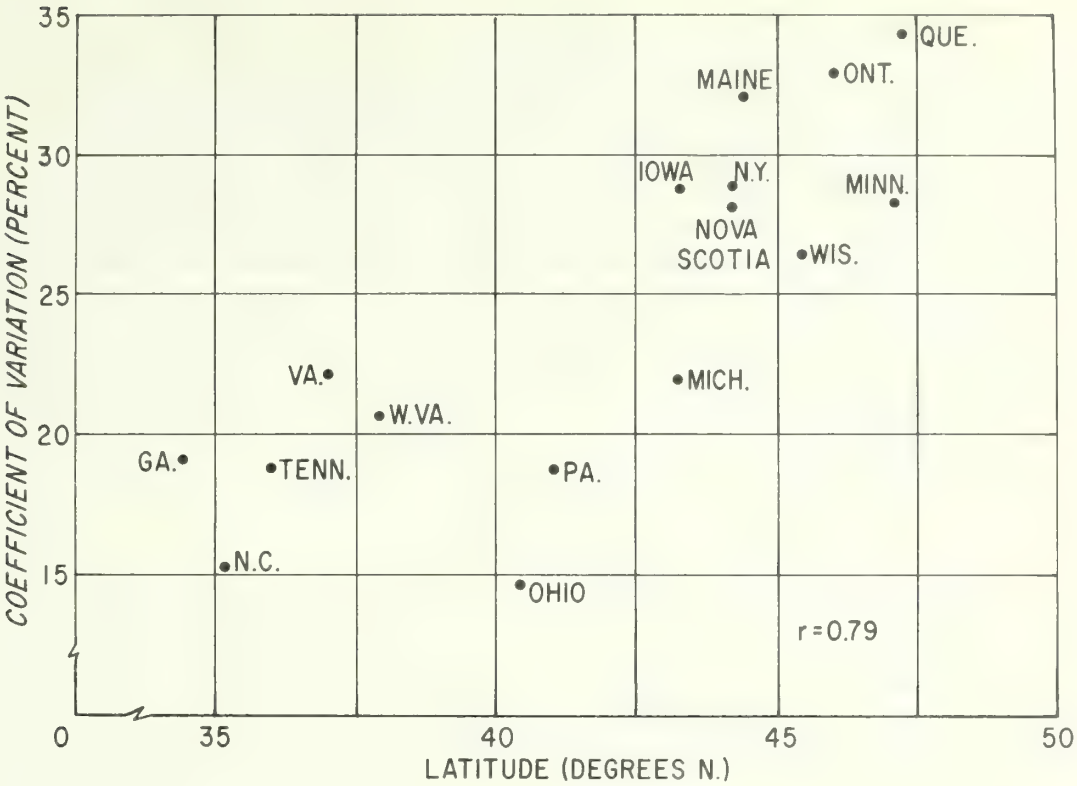

Figure 4.--The relationship between latitudes of the provenances and average coefficient of variation in height of trees within plots at age 10 years for the North Carolina plantation.

In the Georgia plantation, the relationship between latitudes of the provenances and height variation was significant at the 5-percent level ($r = 0.81$ for 5-year data). The relationship was not significant in the Virginia plantation ($r = 0.21$ at 5 years).

Replanting first-year fail-spots with 2-1 stock had no detectable effect on coefficients of variation within plots. The coefficients were plotted over first-year survival, but there was no correlation between them.

DISCUSSION

Height Growth

Rapid height growth apparently did not give rise to eccentric height-over-age curves for any of the provenances (fig. 3). The curves are remarkably uniform and differ only in level and not in shape. Good early performers are still the best and poor ones still the worst. Thus, the factors controlling relationships of height and age are constant among provenances and it is the amount of annual growth that differs.

For white pine planted in Georgia and North Carolina, the choice is clearly in favor of local or Southern Appalachian seed. Eastern Tennessee can also be safely recommended. There are no indications that bringing in seed from other areas would be advantageous.

For planting in Virginia, the choice among provenances is not as definite as for areas further south. In the Virginia plantation, there were no significant differences in height of trees from Georgia, West Virginia, or Pennsylvania. Because not all of the Southern Appalachian provenances were included in the two smaller plantations, the performance in Virginia of trees from North Carolina, Tennessee, and Virginia remains untested. Wright's (1970) evidence of the good growth of Southern Appalachian white pine in plantations farther north, however, indicates that any of these provenances would be satisfactory for planting in the mountain and valley region of Virginia.

Variation Among Trees

Weed competition was relatively uniform within plots in the North Carolina plantation, and the trees were cultivated during the critical first season. Variable competition, therefore, does not seem to be the reason for greater coefficients of height variation in northern trees.

Wright (1970) and Pellati (1967) reported significant differences in growth among progenies of individual white pine trees. Zarger (1965) also reported variation in growth among nursery-selected white pine seedlings. Thus, there is experimental evidence for genetic differences in growth rate among individual white pine trees. Perhaps variation in growth capacity is greater among northern than among southern trees. This variation could arise from differences either in population structure or in the number of generations that white pine has been growing and undergoing natural selection in the respective areas.

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Stimulation of Flower and Seed Production in a Young Slash Pine Orchard

By

Robert P. Schultz

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Stimulation of Flower and Seed Production in a Young Slash Pine Orchard

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INTRODUCTION

Widespread interest in tree improvement has resulted in the establishment of numerous seed orchards in the Southeast. The extensive regeneration programs underway demand that these new orchards be managed intensively for early and abundant seed.

Many treatments and techniques have been used to increase the flower production of trees. Irrigation, fertilization, and mechanical injury (root pruning, girdling, banding) have all stimulated flowering and cone production under certain conditions. Irrigation has improved cone production in longleaf pine (Pinus palustris Mill.) (10, 16). Fertilization and root pruning have significantly improved flowering of young slash pine (P. elliottii Engelm.) (12, 14). Wide varieties of fertilizers and dosages have increased flower and seed production of mature trees (1, 4, 11, 20), but the results have been extremely variable.

In many cases, the application of nitrogen (N) alone has stimulated flowering (5, 6, 13, 16, 18), but the reverse has been noted in some species (15). Several workers have noted that inconsistent flowering of trees might partially be the result of inherent differences in fruitfulness (3, 7, 11, 17, 19). Much work still needs to be done before we can formulate efficient and effective cultural treatments for specific species, areas, and situations.

This paper discusses the effects of heredity and intensive culture (N fertilization, irrigation, disking, and cover cropping) on flower, cone, and seed production during a 5-year period (ages 7, 8, 10, and 11) in a slash pine clonal orchard. In addition, it compares cone production of clonal and seedling stock at age 11.

EXPERIMENTAL DESIGN AND TREATMENTS

The study area, located in northeast Florida on a well-drained flatwoods soil (Klej fine sand) formerly under cultivation, was installed in 1957 and 1958 in a split-plot 2^3 factorial design. The following cultural treatments were begun in 1960:

Irrigation (split plot):

A. No addition to the average 132 cm. of rainfall per year.

B. Irrigation to provide at least 5 cm. of total water (rainfall plus irrigation) per week from March through November, and at least 2.5 cm. per week from December through February.

Fertilization:

A. No fertilizer.

B. Ammonium nitrate was broadcast at 168 kg. N/ha., in the spring of both 1964 (age 6) and 1967 (age 9).

Soil cover:

A. Disking to a depth of 12 cm. four times annually until 1965, but only twice annually from 1965 to 1969.

B. Cover crop of hairy indigo (Indigofera hirsuta L.) maintained until 1966; legumes were subsequently shaded out by the pines.

There were no untreated control plots; comparisons were made among the factorial combinations of treatments.

A set of 24 ramets (1 from each of 24 clones) comprised a plot for the environmental treatments. The experiment was replicated three times; thus, it contained a total of 24 × 8 × 3 = 576 ramets. The plots were separated by one or two rows of commercial seedlings, and all trees were planted at 6- by 6-m. spacing.

The clonal stock was air layered from 11-year-old ortets of known parentage and oleoresin-yielding potentials. All ortets, grown in a nearby progeny test plantation, were control-pollinated or wind-pollinated progeny of trees growing within 160 km. of the study area.

In February 1965 and 1966 (ages 7 and 8), all female flowers on each tree were counted from above by using two ladder trucks. In 1965, the catkin clusters were counted on the western one-fourth of the circumference of each tree and multiplied by four to estimate total production. In 1966, all catkin clusters were counted on each study tree. In February 1968 and 1969 (ages 10 and 11), all female flowers and catkin clusters were counted on four randomly selected clones (96 trees). In the fall of 1966 and 1969, all sound cones were removed, bagged separately by tree, and dried on screens. The seed were cleaned, and the sound seed were counted. The 1966 seed were weighed to the nearest 0.01 gram.

In addition, all mature 1969 cones were counted on six ramets of the remaining 20 clones and 113 isolation seedlings to compare overall cone production of clonal and seedling stock.

RESULTS AND DISCUSSION

Catkin clusters.--Clones produced significantly different numbers of catkin clusters. (All significant differences are at the 0.05 level of probability.) Eight clones bore fewer than nine clusters per tree at age 7 (1965), and eight others bore over 80 clusters per tree (table 1). At age 8 (1966), all clones averaged eight or more clusters per tree and 14 averaged over 80 clusters per tree. This, combined with the fact that twice as many catkin clusters were produced at age 8 as at age 7, indicates these clones were just coming into heavy male flower production. At ages 10 and 11, three of the four clones examined had an average of 190 or more catkin clusters per tree and overall production was twice that of 8-year-old trees.

At age 7, 15 of the 24 clones had more than twice as many catkin clusters when irrigated than when not irrigated. Irrigation also increased the number of flowers on three clones by 65 percent but did not affect flowering on six others. This clone x irrigation interaction was statistically significant. At age 8, most clones had essentially the same number of catkin clusters under irrigated and nonirrigated conditions, probably because very little irrigation was applied the previous year (1965). During the 10th and 11th years most clones showed significant negative responses to irrigation.

Several cultural treatments or combinations significantly altered male flower production, but in each case the treatments were not effective beyond age 8. Cover cropping plus no fertilization produced only 42 catkin clusters per tree at age 7; other combinations produced from 58 to 62 clusters per tree. Disking increased male flower production over cover cropping by 20 percent at age 8. Trees which were cover cropped, but not fertilized or irrigated, produced the fewest flowers at ages 7 and 8, but the interaction was significant only at age 8. The fact that cultural treatments had little effect on male flower production at ages 10 and 11 suggests that only young trees which have not reached a mature flowering stage can be stimulated into increased male flower production.

At age 8, all treatments averaged more than 71 catkin clusters per tree, or approximately 196,000 catkins per ha. Flowering of this magnitude should not limit seed production. Thus, treatments specifically designed to increase pollen production may not be warranted in slash pine clonal stock older than 8 years.

Male flower production was not related to the oleoresin-producing capacity of the clones.

Female flowers.--There were significant differences in the fruitfulness of clones during the 4 years of study. At age 7, 12 clones bore fewer than five female flowers per tree while six others produced 20 or more

Table 1.--Flower, cone, and seed production of 7- and 8-year-old clones of slash pine

Clone designation	1965 flowers per tree		1966 cones per tree	Seed per cone	Average seed weight	1966 flowers per tree		Relative[2] maleness
	Catkin clusters	Female flowers				Catkin clusters	Female flowers	
	------Number-------				Mg.	-----Number-----		
LOW OLEORESIN-YIELDING CLONES[1]								
A-1	33	0	2.9	7	36	96	0.2	1.00
A-2	68	4.3	3.1	23	36	111	4.7	.95
A-3	27	2.7	1.9	24	42	63	4.5	.93
A-9	93	.9	.1	19	41	209	2.3	.99
Weighted average	55	2.0	2.0	18	37	120	2.9	
AVERAGE OLEORESIN-YIELDING CLONES								
A-4	110	24.0	23.8	11	40	205	23.9	.87
A-8	96	1.6	1.5	59	34	155	1.7	.99
A-10	21	3.9	2.1	28	32	94	6.1	.92
A-11	4	.2	.1	29	48	58	2.0	.97
A-12	158	9.2	4.7	20	36	183	5.9	.96
H-1	241	19.7	10.1	24	37	259	16.6	.93
H-3	6	24.9	10.7	25	41	23	27.1	.36
H-6	8	17.0	5.9	31	35	8	18.9	.31
H-7	0	49.5	50.2	23	37	14	64.4	.11
H-12	24	7.8	3.7	19	30	54	14.5	.78
Weighted average	67	15.8	11.3	21	37	105	18.1	
HIGH OLEORESIN-YIELDING CLONES								
A-5	122	6.3	3.3	14	49	197	26.8	.91
A-6	23	13.2	7.1	13	37	88	31.7	.72
A-7	43	4.9	4.0	20	39	89	5.1	.93
H-2	7	1.9	1.0	45	32	99	29.9	.77
H-4	2	2.5	.9	15	37	26	2.0	.86
H-5	88	.1	0	7	33	124	.1	1.00
H-8	14	.7	.1	41	49	48	.7	.98
H-9	142	33.0	23.2	23	35	219	35.2	.84
H-10	0	55.6	26.7	42	34	9	69.2	.07
H-11	8	91.6	82.3	41	36	73	94.9	.30
Weighted average	45	21.0	14.9	36	36	97	29.6	

[1]Ortets of low-yielding clones yield 3,000 to 4,200 g. of oleoresin per tree per year; average clones yield 5,000 to 8,000 g., and high clones yield 8,200 to 12,200 g.

[2]Average 1965-1966 male flower production divided by average 1965-1966 male plus female flower production.

(table 1). At age 8, nine clones had fewer than five female flowers per tree while nine others had 20 or more. All four clones examined at age 10 averaged 38 or more female flowers per tree; only one of these had previously shown good flower production. These data show that up to age 8 some clones had not reached the physiological stage of flowering but by age 10 most clones were moderate-to-good flower producers.

There were highly significant fertilization x clone interactions at ages 7, 10, and 11. Clones which apparently were physiologically ready to flower responded well to N fertilization at age 7. Female flower production was increased by at least 50 percent on 11 of the 12 clones which bore more than five flowers per tree. Nonflowering clones did not flower, even when fertilized. Three clones had at least 50 percent fewer flowers under fertilized than under nonfertilized conditions. At ages 10 and 11 fertilization increased the flowering of all four clones, but the increases varied over a wide range. In general, the best flower producers were stimulated the most by fertilization.

Oleoresin production of the clones appeared to be related to the average female flower production. The correlation ($r = 0.37$) approached significance and suggested that high oleoresin-producing clones had the greatest number of female flowers per tree.

Table 2.--Effect of nitrogen fertilization on slash pine flower and cone production

Treatment	Tree age			
	7	8	10	11
FEMALE FLOWERS PER TREE				
Fertilization[1]	22*	21	116*	36
No fertilization	9*	20	35*	16
MATURE CONES PER TREE				
Fertilization[1]	--	16*	--	66*
No fertilization	--	7*	--	21*

[1]168 kg. N/ha. as ammonium nitrate applied at age 6 and age 9.
*Significant at the 0.05 level.

Applying N at age 6 more than doubled the number of female flowers 1 year later, confirming the results reported earlier for a portion of this plantation (2). However, fertilization did not increase production the second year (table 2). A subsequent application at age 9 tripled the number of flowers at age 10; it also doubled the number of flowers at age 11, but a significant clone x fertilization interaction rendered the increase nonsignificant. These results suggest that most of the added N was used by the trees shortly after application, with the possibility of some recycling at age 10. This is substantiated by the fact that the N level in the surface 15 cm. of the soil was the same 1 year after each fertilization as it was prior to treatment. Also, the trees rooted to depths greater than 2 m., indicating the fertilizer was not leached below the rooting zone.

Irrigation significantly reduced flowering at ages 10 and 11. In both cases, irrigation during the preceding summer exceeded 43 cm. of water. At ages 7 and 8, irrigation did not affect flowering and in each case there was essentially no irrigation applied to the trees during the preceding summer. These results, plus the fact that male flowering followed the same

trends, support earlier results in this plantation[1] and work of Dewers and Moehring (9), which indicate that late summer water stress may be conducive to cell differentiation into reproductive tissues.

Relationship of male to female flowers.--Nineteen of the 24 clones showed a strong tendency toward maleness at ages 7 and 8 (table 1, fig. 1). There were only three heavy female flower producers and none produced many male flowers. Of the eight clones producing over 100 catkin clusters per tree, only one had more than 24 female flowers per tree. At ages 10 and 11 the tendency toward maleness was still clearly evident but somewhat weaker.

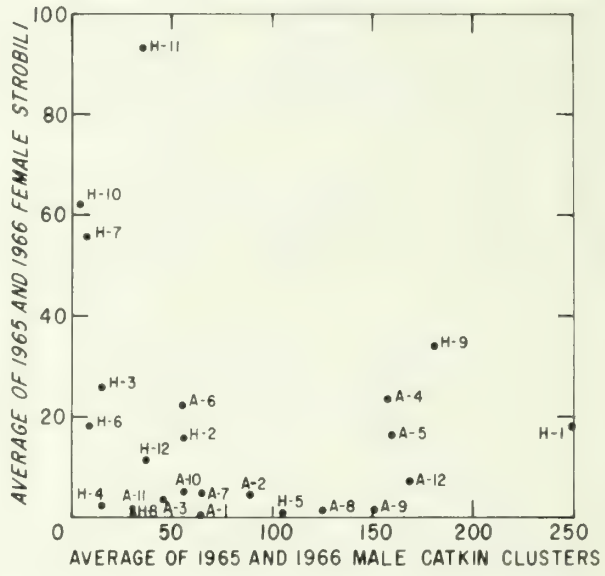

Figure 1.--Genetic effects on male and female flower production of 7- and 8-year-old slash pine. Each letter-number identifies a clone.

Cones.--Mature cone production at ages 8 and 11 closely followed female flower development the preceding years (tables 1 and 2). Fertilization more than doubled the cone crop at age 8 and more than tripled it at age 11. Clones differed significantly in cone production, and some clones responded more to fertilization than others. By age 11, one-half the clones produced over 30 cones per tree without supplemental fertilization.

The mortality which occurred between initial counting of flowers and the harvest of mature cones was not significantly affected by cultural treatments. Overall, 71 percent of the 1965 ovulate flower crop and 58 percent of the 1968 crop developed into sound seed-producing cones. These figures may be high because the flowers were not counted until the vegetative growth had protruded far enough beyond the needles to make counting accurate and easy. Thrips (Gnophothrips piniphilus Cwfd.) can infect and

[1]Unpublished data on file at the Naval Stores and Timber Production Laboratory, USDA Forest Service, Olustee, Florida.

kill up to 38 percent of the flowers in the early stages of development (8). Other factors, such as wind and perching birds, also may have taken a toll of the flowers prior to counting.

Number of sound seed per cone.--There were statistically significant clonal differences in the number of seed per cone. At age 8, the number of seed per cone ranged from 11 to 42, where there were at least five cones per tree (table 1). At age 11, the clonal range was from 24 to 52 seed per cone.

At age 8, the combination of fertilization plus irrigation yielded 36 seed per cone, as compared with 22 for fertilization without irrigation; at age 11 the same treatments had 50 and 27 seed per cone, respectively. This interaction was significant the first year and approached significance the second year. No other treatments or combinations affected the number of seed per cone. These results indicate that, where N is applied to stimulate cone production, it may be desirable to irrigate during the period of ovule fertilization (early spring) to get the greatest number of seed per cone.

Average seed weight.--The average clonal seed weight ranged from 30 to 49 mg. (table 1). For clones bearing five or more cones per tree, however, the range was only 34 to 41 mg. Trees which were irrigated and fertilized had more seed, but they were 6 percent lighter than the seed of nonirrigated and fertilized trees. Leguminous cover cropping increased the average seed weight by 9 percent, when compared to disking. Also, the average seed weight from nonfertilized trees was 2 percent greater than from fertilized trees. All these differences were statistically significant, but the inherent differences far outweighed the differences due to cultural treatment.

Table 3.--Average cone yield for slash pine air layers and seedling stock (age 11)

Item	Air layers	Seedlings
	--Number--	
Trees examined	144	113
Trees bearing cones	132	76
Cones/tree	69	13
Cones/bearing tree	75	19

Cone production of clonal vs. seedling stock.--Air layers had five times as many cones per tree and four times as many cones per bearing tree than did isolation trees of the same age grown from seed (table 3). These data suggest that seedling orchards may not be as productive as clonal orchards, at least through age 11.

CONCLUSIONS

Young slash pine clones vary greatly in precociousness, fecundity, sex, and response to irrigation and fertilization. At ages 7 to 8, some clonal lines had not reached the physiological stage of flowering, but by age 10 most clones produced a moderate-to-high number of female flowers. Precocious clones could be stimulated into increased female

flower production for at least 1 year by fertilization with ammonium nitrate. The best flowering trees were stimulated the most by fertilization. High oleoresin-producing clones may bear more female flowers per tree than low producers. Fertilization plus irrigation yielded more seed per cone, but lighter seed, than fertilization without irrigation.

Irrigation and disking stimulated male flowering at ages 7 and 8. By age 8 the number of male flowers was large enough so that treatments specifically designed to increase pollen production were not necessary.

Results indicate that the time of irrigation may be critical if maximum flower production is to be achieved. It is not enough to irrigate just when conditions are dry; the physiological stage of tree development must be taken into account. For slash pine clonal stock, it appears best not to irrigate in the late summer--during the formation of flower primordia. However, irrigation may be desirable in the spring of the year--when ovule fertilization occurs.

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Reproductive potentials of clones of Pinus elliottii Engelm. were compared under varying levels of silviculture in northeast Florida. Irrigation plus fertilization yielded the largest number of sound seed per cone. Results indicate that irrigation in late summer may suppress both male and female flower development. Fertilization with nitrogen plus irrigation during the spring may increase the number of seed per cone.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Bibliography on Insects Destructive to Flowers, Cones, and Seeds of North American Conifers

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INTRODUCTION

The purpose of this Bibliography is to list all the literature published through 1970 on insects affecting seed production of North American conifers. Bibliographic items are entered by authors in alphabetical order; the references are not annotated. A Host Index to tree species and a Species Index to insects are included also. The numbers following tree and insect names in the indexes refer to the entry in the Bibliography.

To make the compilation as complete as possible, we included many processed reports and publications of limited distribution. Some of these reports contain considerable information about insect biology and damage evaluation, but most contain only general information. Also included are some taxonomic works concerned specifically with cone and seed insects as well as some of the more important general taxonomic literature; however, no attempt was made to include the complete taxonomic literature dealing with each insect species.

The index to insects includes species known to be primary destroyers of flowers, cones, seeds, and cone-bearing shoots and includes many species about which very little is known of their biology, behavior, and economic importance. Parasites and predators of cone and seed insects are not included in the Species Index.

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Barcia, Dorothy R., and Merkel, Edward P.
1972. Bibliography on insects destructive to flowers, cones, and seeds of North American conifers. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-92, 80 pp.

The bibliography contains literature published and processed reports through 1970 on insects which are known to be, or associated with, the destruction of flowers, cones, and seeds of North American conifers. Included are a Host Index to tree species and a Species Index to insects.

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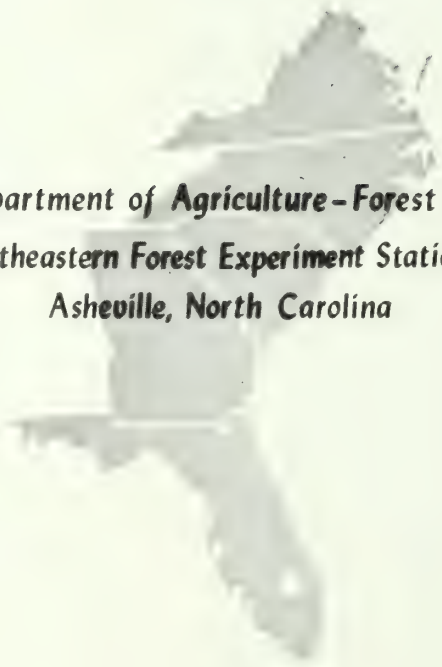

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

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Annotated Bibliography of Publications on Watershed Management of the Southeastern Forest Experiment Station, 1928-1970

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Annotated Bibliography of Publications on Watershed Management by the Southeastern Forest Experiment Station, 1928-1970

by

James E. Douglass, Principal Hydrologist
Coweeta Hydrologic Laboratory
Franklin, North Carolina

INTRODUCTION

This Bibliography was prepared at the request of scientists, educators, students, and land managers seeking information on published results of research on watershed management by the Southeastern Forest Experiment Station. It contains 209 annotated citations of publications on watershed management and the influence of various types of forest cover on streamflow and water yield. All authors listed were staff members of the Station or individuals whose research was supported either in part or entirely by the Station. The Bibliography covers publications issued from 1928 through 1970 and includes some that appeared in early 1971.

The citations are arranged alphabetically and chronologically by author. An asterisk (*) before the citation number indicates that reprints of the publication can be obtained from the Southeastern Forest Experiment Station as long as the supply lasts. As would be expected, a variety of types of papers are involved. These include discussions of research problems and needs; reviews of research programs, objectives, and results; descriptions of instrumentation, analytical procedures, and experimental areas; reviews of research results from different geographical or technical fields; and presentation of results of original research. Immediately preceding the Bibliography is a Subject Index in which each citation is keyed by number to the subject category under which it falls. Some citations have been cross-referenced under several categories.

Recency of publication is not a sure indication of the relevance of the work to contemporary research. In some cases, earlier published results have later been superseded by more complete reports, but some of the earlier reports dealing with analytical procedures, methods, and, in particular, descriptions of the hydrologic functioning of forested watersheds are still classic works in forest hydrology.

Because the emphasis in watershed management has shifted with the changing needs and problems of the times during the 50 years of the Station's existence, a brief historical survey of the program is included for the interested reader. Dr. Charles R. Hursh, who directed this research program at the Station for many years, provided valuable information on the early history of forest hydrology in the Southeast, and his assistance is gratefully acknowledged.

SURVEY OF WATERSHED MANAGEMENT RESEARCH

Interest in forest influences on the environment in the Southeast began before the first decade of this century, when there was much verbal speculation about the effects of forests on climate and public health and on soil and streamflow. Editors and writers discussed these subjects with little or no consideration for accurate technical terminology. The U. S. Army Engineers, who had charge of flood control and levee operations, were critical of such writers, particularly when they made broad, unsupported statements about the effects of forests on streamflow. In a widely read government publication issued in 1909, Major-General Chittenden of the Mississippi River Flood Control project expressed himself forcibly that forests were of no significance in flood control. Then came the Weeks Act of 1911, which led to the creation of the National Forests, and further controversy that reached a high pitch at the time of the disastrous 1927 flood on the Mississippi River. Almost everything written on the favorable effects of forests on streamflow was being questioned.

On July 1, 1921, the Appalachian Forest Experiment Station, later renamed the Southeastern Forest Experiment Station, was established. Its research program was oriented primarily toward study of silviculture, reforestation, and management of forests, as well as forest protection, forest economics, and streamflow and erosion control, although active research in the latter did not begin until 1926.

At that time, livestock was being grazed extensively in the eastern National Forests. Steep mountain land everywhere was being cleared and planted with corn. Logging was done by subcontractors who had little regard for resulting damage to the forest or erosion from skid trails. Local farmers considered pine trees as weeds; depleted and abandoned fields in "broom sage" were called "pastures." Erosion on wornout and abandoned land in the Southeast was regionwide. Such land was not wanted by private individuals and could be bought for delinquent taxes. Nevertheless, the rank and file of professional foresters at the time were not informed on the subject of forest effects on climate and soil, and they were completely inarticulate on the subject of streamflow in terms of total water yield, maximum peak discharge, or minimum flow dependability.

Fortunately, E. N. Munns, of the Forest Service's Branch of Research, had observed and written about land erosion in California prior to his assignment to Washington. Supported by E. H. Clapp, then Chief of Forest Research, Mr. Munns became an effective advocate of better land use and of more in-depth research into forest influences on water yield. He believed that a start could be made through studies relating soil conditions to infiltration and surface stormflow. The Branch of

Research requested a Civil Service examination for ecologists with Ph. D. degrees, and two successful applicants were selected. Dr. Hursh was employed by the Appalachian Station in 1926 and actively directed the Division of Forest Influences until his retirement in 1954.

The first goal of this research program was to define the characteristics of the soil, water, and climate of forested land in the Southern Appalachians. At the time, there were no continuous data on streamflow from small drainages selected as independent hydrologic units, and work was begun to obtain valid data suitable for hydrologic analysis.

Some of the earliest work dealt with erosion control and methods of soil stabilization along roadbanks and on abandoned agricultural land and with study of forest humus types of the region. At the Bent Creek Experimental Forest, plots were established in 1932 to study surface runoff from five representative types of forested or agriculture cover, and an infiltrometer was first used successfully with artificial rainfall. These early studies led to an examination of water movement through the soil profile and to the need for complete watershed instrumentation to provide continuous measurements of streamflow and precipitation.

Dr. Hursh was detailed to visit existing Forest Service installations of lysimeters in operation in the Western States. On the basis of this experience, he sought to locate suitable areas on which the Appalachian Station could conduct comprehensive studies on watershed management. Mr. John Byrne, Forest Supervisor of the Nantahala National Forest, suggested a number of possible sites, and the Coweeta drainage basin near Franklin, North Carolina, was finally selected as the most suitable. In 1933, 3,900 acres (later increased to 5,750 acres) of the Nantahala National Forest were set aside as the Coweeta Experimental Forest. After Station Director C. L. Forsling issued instructions that no manipulations of the forest cover were to take place at Coweeta until after a period of standardization of the gaged watersheds, full responsibility for administration of the Coweeta basin was assumed by the Division of Forest Influences.

Thus, the stage was set for a greatly expanded program in watershed management. It was the programs of the Civilian Conservation Corps and the Public Works Administration during the depression years which provided the manpower and funds for expansion of research activities. At Coweeta, a CCC camp was established at the entrance of the basin, and an intensive program of weir construction was started in 1934. A network of 56 standard rain gages and numerous ground-water wells were established in the basin, and a period of watershed calibration began.

Although no staff appointments were made from the Civil Service register during the years the watershed work at Coweeta Experimental Forest was being established, any properly qualified person could be paid from emergency funds for a 3-month temporary period, and the assignment could be repeated indefinitely. Thus, it was possible to employ a number of graduates in engineering with training in hydrology. Some men with good research ability worked with the project under these terms for several years, and many of these men later rose to positions of importance in their profession.

At Bent Creek Experimental Forest during 1933 and 1934, eight weirs were constructed on watersheds ranging in size from 11 to 774 acres in order to study streamflow on areas with various types of cover. The areas studied included forested, mixed forested and agricultural, abandoned agricultural, and overgazed pasture land. At Bent Creek, the striking differences in peak discharge from abandoned old fields and overgrazed pastures as compared with forested watersheds were so consistent that no further measurements were required after the first few years. Data were put to work immediately by TVA in providing valid coefficients of storm runoff for different types of land use.

A unique opportunity to study modifications in local climate and streamflow as a result of removal of the forest cover presented itself at nearby Copper Basin, Tennessee. There, sulfur dioxide fumes from open-hearth smelting of copper ore had killed extensive areas of native forests in the 1800's--one of the earliest and best known examples of air pollution in the Southeast. Death of the forest had created three concentric zones in the basin. The center was completely denuded and severely eroded. A belt of grassland surrounded this zone, and, in turn, the grassland merged with the native forest. Three meteorological stations were installed in 1935, and three more were installed in 1936. Two watersheds were gaged in each zone, and records were collected from 1935 until 1940. Forest Service activities were terminated in 1940, although TVA continued meteorological observations at Copper Basin for several more years.

By 1940, calibration of watersheds at Coweeta was far enough along on some catchments to begin treatments, and a period of experimentation began. Since 1940, watershed experiments have been conducted at Coweeta. Documentations have been made of the harmful effects of certain land-use practices, such as mountain farming, woodland grazing, and unrestricted logging, on soil and water resources. Water-yield experiments designed to measure effects on streamflow of complete or partial forest cuttings and conversion from one type of cover to another have provided conclusive evidence that water yield is influenced by the type and characteristics of the vegetative cover. The knowledge gained in these early experiments later served as a basis for a pilot test of intensive multiresource management of Southern Appalachian forests and has provided guidelines for watershed management on public and private land alike.

By 1945, the primary objectives at Bent Creek had been fairly well achieved, and, because of a lack of manpower and funds for the area, watershed management studies were terminated there. The following year, the 12,000-acre Calhoun Experimental Forest near Union, South Carolina, was set aside for study of the relationships between forests, soils, and streamflow in the agriculturally depleted and severely eroded Piedmont. These studies were aimed at restoring and maintaining favorable conditions for water storage in the soil profile, stabilizing soils and revegetating barren, eroding gullies, inventorying water use and storage of soil moisture by typical vegetative cover types, and determining the effect of different forestry and related land-use practices on the volume, quality, and timing of streamflow. Four small watersheds were instrumented in 1950 and were operated for 12 years. In 1962, the soils project at Calhoun was transferred to the new Forestry Sciences Laboratory at Research Triangle

Park, North Carolina, and the research concerned with watershed management was consolidated with and centered at the Coweeta Hydrologic Laboratory.

The same year, watershed management activities in the Southeast were extended into the Coastal Plains, where there are millions of acres of wetland forests comprised of swamps, wet flats, bays, and bottom lands. Once viewed as a curse to the roadbuilder and logger trying to extract timber, these wetland forests are now recognized as major sources of water, wildlife, timber, and recreation in the Southeast. Knowledge of the hydrologic and other environmental consequences of management of wetlands was required in order to improve water management practices in wetland forests, and a research project on Wetland Forest Soil Improvement was established at Charleston, South Carolina. Four weirs were established to gage flow from 400- to 11,000-acre wetland drainages, and ground-water levels are now monitored at 30 shallow wells on the Santee Experimental Forest near Moncks Corner, South Carolina.

Watershed management research in the Southeast is currently underway at the Coweeta Hydrologic Laboratory and at Charleston. The mission of the Coweeta program is to develop sound principles and prediction methods to guide effective management of Southern Appalachian and Piedmont watersheds for improved water yield and for protection of environmental quality. The mission of the wetlands research program is to develop effective and reliable techniques of water control and soil management for wetland forests. Major problems of the wetlands are to define the hydrology of major physiographic wetland types and to determine the effects of water control measures and vegetative manipulation on hydrology and soil properties.

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5. Physical and Chemical Properties: 15, 16, 29, 31, 69, 70, 73, 77, 91, 111, 114, 119, 125, 133, 158, 165, 167, 169, 201.

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7. Water Regulation and Drainage: 4, 126, 127, 128, 130, 131, 132, 137, 139, 198, 199, 200, 209.

G. Ground Water: 46, 48, 56, 74, 81, 105, 111, 192, 205.

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1951. The Coweeta story. Farmers Fed. News 31(12): 9, 44-45, 48.

Reasons for establishment of the Coweeta Hydrologic Laboratory are given, the research area is described, and studies concerning the effects of mountain farming, woodland grazing, and cutting of vegetation on streamflow are discussed.

(2) _____
1953. Woods grazing may be bad. Prog. Farmer Ga.-Ala.-Fla. Ed., January, p. 111.

Cattle gains, vegetative growth, and soil relations on a forested Appalachian watershed after 11 years of cattle grazing are reviewed.

(3) _____
1956. We learn about little waters of Coweeta. Forest Farmer 16(2): 20-21.

Experiments at Coweeta are pictorially described.

(4) Bay, R. R., and Klawitter, R. A.
1964. What's new in wetland hydrology. Soc. Am. For. Proc. 1963: 175-177.

A discussion is presented on wetland forests, their use, and Forest Service research efforts underway in the southeastern Coastal Plain and the Lake States.

(5) Bennett, J., and Fletcher, P. W.
1947. Loblollies and the land. Soil Conserv. 13(5): 115.

Survival, diameter, height, and volume of loblolly pine near Waterloo, South Carolina, were directly related to land classes based partially on soil differences; the better the land classes, the better the growth.

(6) Biswell, H. H., and Hoover, M. D.
1945. Appalachian hardwood trees browsed by cattle. J. For. 43: 675-676.

Cattle are selective in the tree species they browse. Percentage breakdowns by species are given for the foliage eaten by cattle on a 145-acre Appalachian watershed during 1941 and 1942. Herb utilization approached 100 percent after 1 year of grazing, and the grazing capacity of the watershed was reduced by 50 percent during 1 year of browsing.

(7) Black, P. E.
1957. Interception in a hardwood stand. M.F. Thesis, Univ. Mich. Sch. Nat. Resour., 90 pp.

Gross rainfall, throughfall, stemflow, and interception of rainfall by selected yellow-poplar and hickory trees were measured at the Coweeta Hydrologic Laboratory for 1 year. Equations are presented for predicting stemflow from gross precipitation and crown area and for predicting throughfall from gross precipitation. Throughfall for the year was about 73 inches, and gross precipitation was 82 inches. For unknown reasons, trees tended to segregate into two groups in relation to stemflow, one group yielding almost double the stemflow of the other.

(8) Black, P. E.
1959. Interception of rainfall by a hardwood canopy. Univ. Istanbul, Orman Fak. Derg., Ser. A, 9(2): 218-224.

Results of studying rainfall intercepted by cove hardwoods growing on an old field are discussed, and equations for determining throughfall during fall, winter, spring, and summer are presented. Estimates of the number of throughfall gages required for interception studies in similar stands are given.

*(9) _____ and Clark, P. M.
1958. Timber, water, and Stamp Creek. USDA Forest Serv. Southeast. Forest Exp. Stn., 12 pp.

This illustrative brochure outlines the proper logging techniques used in a timber sale on the Chattahoochee National Forest, Stamp Creek, Georgia. A satisfactory profit was realized by the logger without serious erosion or damage to the streams and fish.

(10) Boyer, J. S., and Knipling, E. B.
1965. Isopiestic technique for measuring leaf water potentials with a thermocouple psychrometer. Natl. Acad. Sci. Proc. 54(4): 1044-1051.

This new technique for determining rate of vapor flux between thermocouple and leaf is free of error caused by leaf resistance. The method can be used to measure leaf resistance directly and gives more accurate measurements of water potential than do other methods.

(11) Brater, E. F.
1937. An application of the unit hydrograph principle to small watersheds. Ph. D. Thesis, Univ. Mich., 56 pp.

Conversion of unit hydrographs from 22 Appalachian streams to a composite distribution graph with a common time base revealed that the graphs from the various watersheds varied considerably in shape; peak runoff percentage and basal width of the graphs were related to watershed area, and the effect of vegetative cover on runoff was pronounced. Pluviographs from three streams indicated that the composite distribution graphs are a true reflection of the runoff to be expected from a watershed. Study of rainfall intensity and time required for stormflow to recede indicated that variations in intensity have greater effect on lightly vegetated than forested areas. The effect of previous rainfall on stormflow decreased with time on grassy and forested watersheds, the effect being greatest on the latter.

(12) _____
1939. The unit hydrograph principle applied to small watersheds. Am. Soc. Civ. Eng. Proc. 65: 1191-1215.

Tests of the applicability of the unit hydrograph principle on 22 small watersheds ranging from 4 to 1,877 acres lead the author to conclude that this method is one of the best practical devices for predicting flood flows.

(13) Craddock, G. W., and Hursh, C. R.
1949. Watersheds and how to care for them. U. S. Dep. Agric. Yearb. 1949: 603-609.

Hydrologic principles related to forest land use as well as forest protection and management practices which influence the amount, quality, and timing of flow from forest land are discussed.

(14) Croft, A. R., and Hoover, M. D.
1951. The relation of forests to our water supply. J. For. 49: 245-249.

The authors use research findings to show how forest management practices affect the quality, quantity, and timing of water yield and discuss practical implications of forest management on the solution of water problems.

(15) Dils, R. E.
1952. Changes in some vegetation, surface soil and surface runoff characteristics of a watershed brought about by forest cutting and subsequent mountain farming. Ph. D. Thesis, Mich. State Coll. Agric. & Appl. Sci., 205 pp.

Conversion of a 23-acre forested watershed at the Coweeta Hydrologic Laboratory to a mountain farm resulted in changes in vegetation, physical properties of soils, and runoff. Marked and variable differences in infiltration rates, permeability, percentage of water-stable aggregates, organic matter content, volume weight, and pore size distribution of soils were observed in portions of the watershed treated in different ways. Yearly soil losses increased from about 154 pounds per acre under forest cover to well over 1 ton per acre under mountain farming. Storm peaks increased sharply, and volumes of stormflow increased somewhat. Practical implications for land use are discussed.

(16) _____
1953. Influence of forest cutting and mountain farming on some vegetation, surface soil and surface runoff characteristics. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 24, 55 pp.

Infiltration rates, organic matter content, density, and porosity of soils were all adversely affected by conversion of a forested watershed at Coweeta to a mountain farm. Storm runoff volumes, peak discharge rates, flood peak frequencies, and overland flow were all increased. Mountain farming shortly proved to be uneconomical.

*(17) _____
1957. A guide to the Coweeta Hydrologic Laboratory. USDA Forest Serv. Southeast. Forest Exp. Stn., 40 pp.

This report replaces the 1948 guidebook (Item 181) and summarizes the contributions of many researchers who have worked at Coweeta. The area and its water resources are described, and research methods and results are outlined.

*(18) Douglass, J. E.
1960. Soil moisture distribution between trees in a thinned loblolly pine plantation. J. For. 58: 221-222.

Variation in soil moisture is shown to be related to tree location, and associated sampling problems created by unequal moisture distribution in pine plantations are discussed.

(19) _____
1962. A method for determining the slope of neutron moisture meter calibration curves. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 154, 6 pp.

A new water-addition method is presented which allows a check of slope coefficients derived from gravimetric calibrations of neutron moisture probes. Coefficients obtained by the new method differed from those obtained by gravimetric calibration by as much as 36 percent. Differences were attributed to bias arising because drying temperatures used in gravimetric calibration failed to remove all bound water and because the gravimetric method failed to account for differences in neutron absorption between soils.

*(20) _____
1962. Variance of nuclear moisture measurements. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 143, 11 pp.

Several conclusions can be drawn concerning the use of nuclear equipment to measure moisture in Piedmont soils: (1) The error in measuring moisture content is particularly large in soils with varying texture. (2) Analysis of moisture losses, which utilizes covariance techniques to remove the textural effect, is more precise for detecting moisture differences than for determining total moisture content. (3) The error in moisture measurements increases as the range of clay content increases.

*(21) _____
1966. Effects of species and arrangement of forests on evapotranspiration. Natl. Sci. Found. Adv. Sci. Semin., Int. Symp. Forest Hydrol. Proc. 1965: 451-461.

This paper reviews research concerned with the effects of plant species and arrangement on evapotranspiration. In general, grasses use less water than forest species because of the shallower rooting habits of grass; usually, differences in evapotranspiration which occur between forest species could not be detected except where rooting depths were unequal. Evapotranspiration varies with stand density and vegetative height, at least in humid regions, and evapotranspiration probably varies with slope and aspect as well.

*(22) _____
1966. Research at the Coweeta Hydrologic Laboratory. Clemson Univ. Counc. Hydrol., Hydrol. Act. S.C. Reg. Conf. Proc. 1965: 11-17.

The first 30 years of research at the Coweeta Hydrologic Laboratory and plans for future research are discussed.

*(23) Douglass, J. E.
1966. Volumetric calibration of neutron moisture probes. Soil Sci. Soc. Am. Proc. 30: 541-544.

A volumetric method of estimating the slope ($\bar{b}$ coefficient) of the calibration curve for a neutron moisture probe is presented. Coefficients obtained for three probes did not differ significantly between soil series or between horizons within a series. Simply dividing the count rate in water by 100 gave a value virtually identical to the $\bar{b}$ coefficient determined volumetrically for these probes and soils. Agreement was excellent between measured outflow and outflow predicted from neutron measurements made with a volumetrically calibrated probe.

(24) _____
1967. Man, water, and the forest. Forest Farmer 26(5): 6-7, 18, 20.

The interrelationships between man's activities, water, and the forest are discussed.

*(25) _____ Cochrane, D. R., Bailey, G. W., Teasley, J. I., and Hill, D. W.
1969. Low herbicide concentration found in streamflow after a grass cover is killed. Southeast. Forest Exp. Stn., U.S.D.A. Forest Serv. Res. Note SE-108, 3 pp.

Grass cover on an Appalachian watershed was sprayed with atrazine and paraquat and later with atrazine and 2,4-D. Although grass growing in the stream channel was sprayed, atrazine and paraquat levels in water samples were low. During a second application, a 10-foot strip on either side of the channel was left unsprayed; no increase in atrazine and no trace of 2,4-D were detected in streamflow.

(26) Dunford, E. G.
1947. Research in the Central Piedmont. Forest Farmer 6(12): 4, 8.

The establishment of Calhoun Experimental Forest in the Central Piedmont of South Carolina is discussed, and problems resulting from the abused agricultural land as well as the research approach to be followed in rehabilitating the soils are described.

(27) _____ and Fletcher, P. W.
1947. Effect of removal of stream-bank vegetation upon water yield. Am. Geophys. Union Trans. 28: 105-110.

This is a preliminary report on the results of removing stream-bank vegetation from Watershed 6 at the Coweeta Hydrologic Laboratory. Diurnal fluctuations in the streamflow were virtually eliminated. Cutting of riparian growth also resulted in an increase in yield of sufficient magnitude to be significant in water resource management.

(28) Fletcher, P. W.
1949. Better land resource management is coming to the Missouri Ozarks. Univ. Mo. For. Club, Mo. Log 1949, II: 32-35.

A forester describes the improvements which occurred in the forested and agricultural landscape during 11 years of enlightened management.

(29) Freeland, F. D., Jr.
1956. The effects of a complete cutting of forest vegetation and subsequent annual cutting of regrowth upon some pedologic and hydrologic characteristics of a watershed in the southern Appalachians. Ph. D. Thesis, Mich. State Univ. Agric. & Appl. Sci., 182 pp.

Vegetation on one of two calibrated watersheds at Coweeta was cut in 1941, slash was lopped, but no products were removed; thereafter, annual regrowth was cut (except from Sept. 1942 until Feb. 1946). Although soils on the two areas were uniform initially, field and laboratory analyses in 1953 showed a lower percentage of large, water-stable aggregates in the surface soil layers of the treated watershed, as well as a lower water stability of these aggregates. Unincorporated humus on the soil was less on the treated watershed, and the rate of decomposition of humus was accelerating. Dry clods, volume weight and porosity, permeability and field capacity, moisture equivalent, and moisture contents during the growing season were not significantly changed by treatment, but air and soil temperatures were increased. Water yield from 1941 through 1953 on the treated watershed averaged 10 inches higher than was predicted for the uncut watershed. Low flows were increased almost 100 percent, and peak flows were only slightly increased.

(30) Greene, G. E.
1950. Land use and trout streams. J. Soil & Water Conserv. 5: 125-126.

Maximum stream temperatures rose appreciably when a forested watershed at Coweeta was converted to a mountain farm. Because absence of shade can increase stream temperatures, riparian vegetation should be carefully manipulated to maintain optimum temperatures for growth and development of trout and aquatic organisms.

(31) _____
1953. Soil temperatures in the South Carolina Piedmont. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 29, 16 pp.

Data are presented on temperatures at eight depths in the upper 6 feet of soil under a shortleaf pine-hardwood stand, a loblolly pine plantation, broomsedge grass field, and a barren site. Vegetative cover had greatest effect in the summer, and subsurface temperatures decreased as vegetative cover increased. Minimum temperatures at 6 feet varied from 50° to 52° F. regardless of cover.

(32) Grzenda, A. R., Nicholson, H. P., Teasley, J. I., and Patric, J. H.
1964. DDT residues in mountain stream water as influenced by treatment practices. J. Econ. Entomol. 57: 615-618.

DDT residues in Coweeta streams after spraying for elm spanworm by airplane in 1961 and by helicopter in 1962 are compared. DDT contamination of Coweeta Creek was negligible after precise application by helicopter in upslope and ridge areas.

(33) Hassler, W. W., and Tebo, L. B., Jr.
1958. Fish management investigations on trout streams. N.C. Wildl. Resour., Fish Div., Proj. Completion Rep. Proj. F-4-R, 118 pp.

This is a report of the cooperative Dingell-Johnson investigation at Coweeta Hydrologic Laboratory. The report includes an extensive description of bottom fauna and describes the effects of erosion debris and riparian cuttings upon fish life.

*(34) Helvey, J. D.
1964. Rainfall interception by hardwood forest litter in the southern Appalachians. Southeast. Forest Exp. Stn., U. S. Forest Serv. Res. Pap. SE-8, 9 pp.

Moisture interception by hardwood litter was measured during 1961 and 1962. The maximum field water content--water retained against drainage--averaged 215 percent of ovendry weight. About 1 inch of throughfall was required to wet the litter to this maximum. The amount of water evaporated per month from litter was greater during the dormant season. Interception loss during 1962 was about 2.2 inches and the long-term average is estimated to be about 3 inches.

*(35) _____
1967. Interception by eastern white pine. Water Resour. Res. 3: 723-729.

Measurements taken in a 10-, a 35-, and a 60-year-old stand of eastern white pine in the southern Appalachians of western North Carolina were used to derive regression equations for estimating throughfall, stemflow, and the sum of throughfall and stemflow from measurements of gross rainfall. Equations for total interception loss were derived and used to predict total seasonal interception loss (I) from measurements of total seasonal rainfall (ΣP) and number of storms (N). For the 10-year-old stand, $I = 0.05(N) + 0.08(\Sigma P)$; for the 35-year-old stand, $I = 0.05(N) + 0.12(\Sigma P)$; and for the 60-year-old stand, $I = 0.06(N) + 0.18(\Sigma P)$. Total interception loss in white pine increased with stand age, and total loss from all pine stands studied exceeded losses calculated for mature hardwoods.

(36) _____
1968. Reply to Editor Langbein in answer to Professor Miller's comments on "Interception by eastern white pine." Water Resour. Res. 4: 455-456.

This is a rebuttal to comments by Professor Miller on the article "Interception by Eastern White Pine."

(37) _____ (contrib.)
1970. Interception of rain, pp. 89-93. In Representative and experimental basins. An international guide for research and practice, Vol. 4. UNESCO. Haarlem: Henkes-Holland.

Some guidelines are presented for designing studies of rainfall interception in forest vegetation. Methods are presented for sampling gross rainfall, throughfall, stemflow, and litter interception loss. The necessary information is presented for determining a first approximation of the sampling intensity needed to achieve a desired level of accuracy.

*(38) Helvey, J. D., and Hewlett, J. D.
1962. The annual range of soil moisture under high rainfall in the Southern Appalachians. J. For. 60: 485-486.

Observations of soil moisture at Coweeta suggest that forest vegetation at this Laboratory rarely, if ever, suffers true drought. Seasonal changes in soil moisture were strongly correlated with changes in streamflow.

(39) _____ and Patric, J. H.
1965. Canopy and litter interception of rainfall by hardwoods of eastern United States. Water Resour. Res. 1: 193-206.

Results from all available studies of rainfall interception by hardwoods of the eastern United States vary over a small range. Data from past studies were used to develop regression equations describing the relation between gross rainfall, throughfall, and stemflow for eastern hardwood forests during the growing and dormant seasons.

*(40) _____ and Patric, J. H.
1966. Design criteria for interception studies. Symp. Des. Hydrol. Networks. Int. Assoc. Sci. Hydrol. Bull. 67: 131-137.

This report, gleaned from over 50 studies, defines variability of interception parameters and provides sampling designs for obtaining estimates to selected levels of probability for each parameter mean. A new method for estimating stemflow is outlined which greatly reduces variability inherent in the traditional single-tree method. These sampling and analytical methods will help insure that results of different studies are comparable.

(41) Hertzler, R. A.
1938. Determination of a formula for the 120° V-notch weir. Civ. Eng. 8: 756-757.

Design of a 120° V-notch sharp-crested weir for accurate measurement of flows up to 26 second-feet is described. For a 2-foot head, the 120° notch has 1.73 times the capacity of a 90° notch and slightly greater capacity than the 2.6-foot rectangular weir. Weir blades were constructed of $3\frac{1}{2}$- by $3\frac{1}{2}$-inch structural angle iron. The discharge formula was $Q = 4.43\ H^{2.449}$, where Q = discharge in second-feet and H = observed head on weir.

(42) _____
1939. Engineering aspects of the influence of forests on mountain streams. Civ. Eng. 9: 487-489.

This article discusses the objectives of the hydrologic research program at Coweeta, Bent Creek and Copper Basin, the weir instrumentation used, and typical early analyses and applications. The application of Horton's infiltration theory to forest lands which have high infiltration rates is questioned. Unit graph analyses of runoff showed that peak percentages of runoff were inversely related to basin area, basal lengths of the distribution graphs were directly related to drainage area, and that the effects of vegetative cover were reflected in both peak percentages and width of the distribution graphs. A quantitative ranking of peak discharge from four cover types is presented.

*(43) Hewlett, J. D.
1957. Coweeta Hydrologic Laboratory. USDA Forest Serv. Southeast. Forest Exp. Stn., 8 pp.

This booklet describes research conducted at Coweeta to develop practical methods of managing forest land for maximum timber production while providing for flood control and maintaining the quality and quantity of water needed for industrial, municipal, and agricultural uses. Results of watershed clearings, mountain farming, woodland grazing, and proper logging procedures are illustrated.

(44) _____
1958. Pine and hardwood forest yield. J. Soil & Water Conserv. 13: 106-109.

This paper discusses the theoretical concepts and experimental results which indicate that conifers use more water than hardwoods. Two catchment studies of the effect on water yield of converting hardwoods to white pine are described.

(45) _____
1961. Response of fescue to natural moisture gradient on an artificial slope. USDA Forest Serv. Southeast. Forest Exp. Stn. Res. Notes 152, 2 pp.

Minor changes in soil moisture stress on well-watered natural slopes may, in part, account for observed reductions in form and vigor of plants with increasing elevation.

*(46) _____
1961. Soil moisture as a source of base flow from steep mountain watersheds. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 132, 11 pp.

Model studies of unsaturated flow in sloping soil columns show that unsaturated flow of water is an important source of base flow in mountain streams.

(47) _____
1962. Internal water balance of forest trees on the Coweeta watershed. Ph. D. Thesis, Duke Univ., 122 pp.

Measurement of the internal water balance of Cornus florida L., Quercus prinus L., Nyssa sylvatica Marsh., and Oxydendrum arboreum DC. throughout a summer revealed that soil and atmospheric moisture stress were related to variation in leaf-water deficit (WD) as calculated by Stocker's formula. WD was determined on whole leaves and compared to a well-known disk technique. Definite response of WD to soil moisture stress between 0.3 and 2.0 atmospheres was produced within the plots; responsiveness of species decreased in the order listed above. WD was shown to depend jointly on soil and atmospheric moisture stress; C. florida was particularly responsive to both factors.

(48) _____
1964. Letter to editor on article "Groundwater: Definition" by H. E. Thomas and L. B. Leopold. Science 144(3625): 1407-1408.

This letter questions the definition of groundwater used in the article.

*(49) Hewlett, J. D.
1964. Research in hydrology of forested headwaters of the Coweeta Hydrologic Laboratory. Twenty-Ninth North Am. Wildl. & Nat. Resour. Conf. Trans. 1964: 103-112.

The author provides background and review of research in forest hydrology at Coweeta and plans for future staffing and research at the Laboratory.

(50) _____
1964. Water or forest - can we have all we need of both? Front. Plant Sci. 17: 2-3.

The author outlines a recent experiment with a transpiration inhibitor and cites benefits possible if this or related tests succeed.

(51) _____ and Douglass, J. E.
1961. A method for calculating error of soil moisture volumes in gravimetric sampling. Forest Sci. 7: 265-272.

A method for calculating error of soil moisture volumes in gravimetric sampling is presented. Limitations in sampling soil density and percentage of moisture to determine inches of water render the gravimetric method a poor tool for hydrologic research.

*(52) _____ and Douglass, J. E.
1968. Blending forest uses. Southeast. Forest Exp. Stn., U. S. D. A. Forest Serv. Res. Pap. SE-37, 15 pp.

Compatibility of forest management practices on a 360-acre southern Appalachian watershed, along with conflicts among uses, is examined in this unique experiment to determine the feasibility of intensive management for wood, water, wildlife, and recreation. An efficient and stable access system is stressed, and the effect of various woods practices on the four basic resources is rated. Increases are shown in water yield, game forage, quality timber growth, and general use of the area, and some unresolved conflicts among uses of the forest are revealed.

(53) _____ Douglass, J. E., and Clutter, J. L.
1964. Instrumental and soil moisture variance using the neutron-scattering method. Soil Sci. 97: 19-24.

The variance in estimates of soil moisture as determined by the neutron-scattering method is examined and related to field data from two research areas. Instrument and timing errors are shown to contribute insignificantly to the standard error of estimate. Furthermore, their contribution to estimates of moisture change with time is negligible as long as the timing interval used at each observation exceeds 30 seconds.

*(54) Hewlett, J. D., and Helvey, J. D.
1970. Effects of forest clear-felling on the storm hydrograph. Water Resour. Res. 6: 768-782.

A statistical analysis of all major storm hydrographs before and after clear-felling a mature hardwood forest on a 108-acre calibrated catchment revealed that, after felling, stormflow volume was significantly (0.001 level) increased 11 percent overall, or 0.23 inch at the mean stormflow volume of 2.1 inches. Peak discharge increased slightly after felling (about 6 c.f.s.m. or 7 percent at the mean peak flow of 92 c.f.s.m.). Time to peak, recession time, and duration of stormflow were tested to an accuracy within 10 percent of their respective mean values (0.05 level), but no treatment effect was detected. Increases in stormflow as a result of felling ranged from 0 in small floods to 1.9 inches during a record 7-day flood sequence.

*(55) _____ and Hibbert, A. R.
1961. Increases in water yield after several types of forest cutting. Int. Assoc. Sci. Hydrol. Bull. 6(3): 5-17.

Effects of timber and brush removal on water yields from small watersheds are examined in the light of 25 years of hydrologic research at Coweeta.

*(56) _____ and Hibbert, A. R.
1963. Moisture and energy conditions within a sloping soil mass during drainage. J. Geophys. Res. 68: 1081-1087.

A model of a sloping soil profile is used to show that slow, unsaturated flow of soil moisture above the water table furnishes much of the sustained streamflow between storms in mountain land.

*(57) _____ and Hibbert, A. R.
1966. Factors affecting the response of small watersheds to precipitation in humid areas. Natl. Sci. Found. Adv. Sci. Semin., Int. Symp. Forest Hydrol. Proc. 1965: 275-290.

A numerical rating system, the response factor, was developed from precipitation and streamflow records for use in classifying the hydrologic response of small watersheds in humid areas. Long-term hydrograph records from 15 forested watersheds in the eastern United States were separated into quick and delayed flow by computer and ranked according to mean precipitation, quick flow, and the response factors quick flow/precipitation and quick flow/total water yield.

(58) _____ and Kramer, P. J.
1963. The measurement of water deficits in broadleaf plants. Protoplasma 57: 381-391.

A comparison of the disk technique with Stocker's whole leaf method for determining water deficit of some hardwood trees reveals confusion in existing terms and methods. The water relations of leaf disks cut from broadleaf trees cannot be assumed to be the same as whole leaves, because more water per unit weight is usually required to saturate excised disks. Stocker's term wasser defizit (WD) and the whole leaf method, when modified to allow shorter equilibration schedules, remain the best way to express and measure water deficits in forest trees.

(59) Hewlett, J. D., and Metz, L. J.
1960. Watershed management research in the Southeast. J. For. 58: 269-271.

This article is a review of research on watershed management at the Coweeta Hydrologic Laboratory and Union Research Center.

(60) _____ and Patric, J. H.
1963. An example of multiple use on a small mountain watershed. 7th Annu. Meet. Ga. Chapter Soil Conserv. Soc. Am. Proc. 3: 12-26.

An example of multiple use on a 356-acre watershed at Coweeta Hydrologic Laboratory is presented. This report discusses the concept of forest access as being the key to management. Plans for management of the area for water, timber, wildlife, and recreational values are presented.

(61) _____ and Patric, J. H.
1963. A pilot test of multiple use on a small mountain watershed. 42nd Annu. Meet. Appalachian Sect. Soc. Am. For. Proc., pp. 11-18.

A pilot test of the multiple-use concept on a 356-acre watershed at Coweeta Hydrologic Laboratory is presented. This report discusses that concept in terms of management of the area for water, timber, wildlife, and recreational values. A proper access system is cited as the key to effective resource management.

(62) Hibbert, A. R.
1961. A study of commonly used hydrologic concepts and their application in runoff analysis on small mountain watersheds. M.S. Thesis, Utah State Univ., 80 pp.

Analysis of hydrograph records from six small mountain watersheds at Coweeta indicated that lag time is apparently the most meaningful of the time elements of runoff. The unit hydrograph method of runoff prediction proved adequate for channel precipitation but gave poor results when applied to overland flow. No concept or method of runoff analysis was found which would adequately describe or predict behavior of subsurface stormflow.

*(63) _____
1966. Forest treatment effects on water yield. Natl. Sci. Found. Adv. Sci. Semin., Int. Symp. Forest Hydrol. Proc. 1965: 527-543.

Results are reported for 39 studies of the effect of altering forest cover on water yield. Taken collectively, these studies reveal that forest reduction increases water yield and that reforestation decreases water yield.

*(64) Hibbert, A. R.
1969. Water yield changes after converting a forested catchment to grass. Water Resour. Res. 5: 634-640.

After a forested catchment was converted to grass, the amount of evapotranspiration was closely related to the amount of grass produced. During years when grass production was high, water yield from the catchment was about the same as or less than the expected yield from the original forest. As grass productivity declined, water yield gradually increased until it exceeded the predicted yield from the forest by over 5 inches annually. The grass appeared to evaporate more water early in the spring and less water late in the summer than the original forest cover.

(65) _____ and Cunningham, G. B.
1966. Streamflow data processing opportunities and application. Natl. Sci. Found. Adv. Sci. Semin., Int. Symp. Forest Hydrol. Proc. 1965: 725-736.

The techniques used at the Coweeta Hydrologic Laboratory for processing streamflow records from recorder charts and analog-to-digital recorder tape to final integration of discharge are discussed in detail.

(66) Hilmon, J. B., and Douglass, J. E.
1968. Potential impact of forest fertilization on range, wildlife, and watershed management, pp. 197-202. In Forest fertilization theory and practice symposium 1967. Tenn. Val. Auth., Muscle Shoals, Ala.

This paper reviews current information concerning the impacts of forest fertilization on forage, wildlife, and water resources.

(67) Hoover, M. D.
1944. Effect of removal of forest vegetation upon water yields. Am. Geophys. Union Trans., Part VI: 969-977.

A clearcutting experiment on Coweeta Watershed 17 is described, and effects of the cutting and subsequent treatment on increasing water yield are presented. Peak discharges were not significantly increased by the cutting, and surface runoff did not occur after treatment. Data indicate that a forest stand annually transpires 17 to 22 inches of water.

(68) _____
1945. Careless skidding reduces benefits of forest cover for watershed protection. J. For. 43: 765-766.

Careless skidding creates channels which concentrate runoff from road surfaces and cause erosion which is unnecessary if roads are carefully located and constructed. Techniques which minimize erosion from skid roads are presented.

(69) _____
1950. Hydrologic characteristics of South Carolina Piedmont forest soils. Soil Sci. Soc. Am. Proc. 14: 353-358.

In this study, capillary and noncapillary pore space and retention and detention storage in a badly depleted Vance soil and in a forest soil were compared. The hydrologic significance of the differences between soils and the need for restoration are discussed.

(70) Hoover, M. D.
1952. Influence of plant cover on soil moisture in the Piedmont. (Abstr.) Assoc. South. Agric. Work. Proc. 49: 172.

Data are presented which show the relationship between vegetative cover and surface runoff in the South Carolina Piedmont.

(71) _____
1952. Water and timber management. J. Soil & Water Conserv. 7: 75-78.

As demand for water increases, management of forested headwaters assumes greater importance. Compatibility of objectives in the management of timber and water is demonstrated, and management practices which protect the values of each resource are stressed.

*(72) _____
1953. Interception of rainfall in a young loblolly pine plantation. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 21, 13 pp.

The following regression equations were developed from measurements of interception loss in a 10-year-old plantation of loblolly pine in the South Carolina Piedmont: Throughfall = 0.732 (rain in open) - 0.016; stemflow = 0.222 (rain in open) - 0.018; and net rainfall to forest floor = 0.954 (rain in open) - 0.034.

(73) _____ and Hursh, C. R.
1943. Influence of topography and soil depth on runoff from forest land. Am. Geophys. Union Trans., Part II: 693-698.

Data are presented on rainfall and discharge for seven watersheds at Coweeta during a storm on December 27-29, 1942. The difference in peak discharges is assigned in part to higher rainfall at higher elevations, but peaks were also related to soil depth, topography, and hydrologic characteristics associated with different elevations.

(74) _____ and Hursh, C. R.
1943. Installation of shallow observation wells. USDA Forest Serv. Appalachian Forest Exp. Stn. Tech. Note 56, 5 pp.

The location, installation, and operation of shallow ground-water observation wells are described. This Note is of value to field personnel involved in well installation and in the analysis of observations taken from wells constructed by the methods described.

(75) _____ and Lunt, H. A.
1952. A key for the classification of forest humus types. Soil Sci. Soc. Am. Proc. 16: 368-370.

A key is presented for classifying major organic layers into Mull, Duff Mull, and Mor. It is applicable for well- and moderately well-drained soils. Basic criteria in the classification are (1) presence or absence of an H layer; (2) the degree of incorporation of organic matter into the upper mineral soil; and (3) the structure, thickness, and organic content of the H layer and the A horizon.

(76) Hoover, M. D., Olson, D. F., Jr., and Greene, G. E.
1953. Soil moisture under a young loblolly pine plantation. Soil Sci. Soc. Am. Proc. 17: 147-150.

The moisture regimen (as determined by the resistance method) of the soil at depths of 0 to 15, 15 to 30, 30 to 42, 42 to 54, and 54 to 66 inches beneath a 12-year-old loblolly pine plantation in the South Carolina Piedmont is described. During the growing season, moisture was lost from throughout the upper $5\frac{1}{2}$ feet of soil. Water was withdrawn most rapidly from the zone where it was most readily available, regardless of depth.

*(77) _____ Olson, D. F., Jr., and Metz, L. J.
1954. Soil sampling for pore space and percolation. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 42, 28 pp.

This report summarizes and describes equipment which has been developed to collect soil cores and methods for measurement of pore space and percolation rates.

(78) Hursh, C. R.
1928. Litter keeps forest soil productive. South. Lumberman 133(1734): 219-221.

Forest soils are, for the most part, self-fertilized by organic material derived from litter. Litter has a beneficial effect on the ability of soil to absorb and retain moisture, on chemical characteristics, and on biological activity. The effects of fire and aspect on litter production are discussed.

(79) _____
1931. Abandoned mountain farms an erosion menace but a forestry opportunity. Farmers Fed. News 11(12): 3, 5.

The author describes agricultural practices which leave mountain soils exposed to erosion and recommends that slopes unsuitable for agriculture not be cleared and that abandoned land be converted to pasture or forest cover to prevent erosion.

(80) _____
1935. Control of exposed soil on road banks. USDA Forest Serv. Appalachian Forest Exp. Stn. Tech. Note 12, 4 pp.

Increased erosion, siltation, and road maintenance can be largely eliminated by covering road banks with litter or revegetating banks at the time of road construction. The simplest and most practical measures include planting, seeding, and use of stake and brush wattles. Selection of suitable plant species is discussed.

(81) _____
1937. Frog makes record. USDA Forest Serv. Bull. 21(16): 6.

The recording of the journeys of a small frog on the float of a water-level recording instrument in a ground-water observation well is described.

(82) Hursh, C. R.
1937. Runoff measurements from eroded land. Tenn. Val. Sect. Am. Soc. Civ. Eng. 1937: 12 pp.

Frequency distributions of peak discharge, rainfall intensity, and stormflow volume as a percentage of rainfall are presented for three experimental locations in the Blue Ridge Mountains. Frequency distributions compared were for denuded land, overgrazed pasture, abandoned farmland, and forested catchments. Prevention and control of runoff are discussed in this early, definitive work on runoff from small watersheds.

(83) _____
1938. Mulching for road bank fixation. USDA Forest Serv. Appalachian Forest Exp. Stn. Tech. Note 31, 4 pp.

Road bank fixation on dry, infertile sites is particularly troublesome, and the use of mulches on dry and infertile banks at the time banks are planted is the most successful and inexpensive method of stabilization. Transplanting of woody shrubs offers no particular problem. Two general methods of mulch application are (1) staked weed mulches and (2) staked brush and litter mulches. The author lists materials, equipment, labor requirements, and procedures for mulch application.

(84) _____
1939. Roadbank stabilization at low cost. USDA Forest Serv. Appalachian Forest Exp. Stn. Tech. Note 38, 20 pp.

Low-cost methods of establishing vegetation on cut-and-fill slopes of roadbanks are described. Planting and seeding without preliminary stabilization are too expensive for extensive use. Two types of mulch application--staked weed mulches and staked brush and litter mulches--are outlined. Requirements for labor and equipment are listed, and procedures for mulch application are discussed.

(85) _____
1940. Outline for compiling precipitation and runoff data from small drainage areas. USDA Forest Serv. Appalachian Forest Exp. Stn. Tech. Note 34, 59 pp.

This is the original description of procedures used by the Station for the systematic compilation of continuous records of precipitation and stream discharges.

(86) _____
1941. The geomorphic aspects of mudflows as a type of accelerated erosion in the Southern Appalachians. Am. Geophys. Union Trans., Part II: 253-254.

Under certain conditions, high infiltration rates and deep soils give rise to conditions which cause mudflows. After prolonged rainfall, the soil mass is surcharged with water; a major surface break, such as uprooting of large trees, may start mass movement. The nature of movement of the soil mass depends on the slope of the contact zone with stable material.

(87) Hursh, C. R.
1942. The naturalization of roadbanks. Roads & Bridges (Can.) 80(7): 22-26, 131-137.

Naturalization and stabilization of roadbanks by vegetation are discussed as part of road construction. Experiments begun in 1934 at the Appalachian Forest Experiment Station indicate that seeding, planting, fertilizing, and mulching are methods of stabilizing banks.

(88) _____
1942. The naturalization of roadbanks. USDA Forest Serv. Appalachian Forest Exp. Stn. Tech. Note 51, 36 pp.

The problems involved in natural stabilization of roadbanks, including the factors limiting plant growth and the origin and causes of soil stability, are discussed. Suggestions are given for stabilization of banks with different slopes and with moist, fertile soil and dry, infertile soil. Establishment of vegetation with commercial fertilizers, seeding, planting, and mulches is discussed.

(89) _____
1943. Discussion of paper entitled "Determination of the effects of watershed-management on mountain streams" by C. L. Wicht. Am. Geophys. Union Trans. 1943: 606-608.

Elimination of the effects of climatic variability and factors such as size, shape, and soil-depth of watersheds through various statistical methods is questioned. Statistical methods are recognized as valuable research tools, but in order to develop practical watershed management techniques, the very factors to be eliminated in the experimental design must be evaluated. The concept of watershed standardization over a period of years is discussed as a procedure which eliminates comparison of the physical characteristics of one watershed with those of another.

(90) _____
1944. Appendix B--report of sub-committee on subsurface-flow. Am. Geophys. Union Trans., Part V: 743-746.

Literature on subsurface flow is reviewed, and the lack of records from suitable experimental watersheds is cited as a handicap in interpreting the nature of subsurface stormflow.

(91) _____
1944. Water storage limitations in forest soil profiles. Soil Sci. Soc. Am. Proc. 8: 412-414.

At Coweeta, measurements of macro-pore space were used to estimate differences in water storage between natural forest soil and soil from pine stands on eroded old-field land.

(92) Hursh, C. R.
1945. Plants, shrubs, trees in slope stabilization. Contract. & Eng. Mon. 42(6): 26-27.

Natural vegetation is the most efficient and esthetically pleasing means of roadbank stabilization. Deep-rooted legumes such as perennial lespedeza and Scotch broom together with native woody shrubs are advised. In the Eastern States, rainfall and site conditions favor a plant succession toward a forest cover, but the possibility of trees being uprooted or interfering with viewing distance should be taken into account.

*(93) _____
1946. The eastern forester and his watersheds. J. For. 44: 1037-1040.

The author pointedly questions whether the average forester is trained to manage water resources of the forest. Basic concepts of geophysical science (soils, climatology, and the origin and distribution of water on the earth's surface) are discussed in relation to the water resource and its management.

(94) _____
1946. Water resources of South Carolina. (Abstr.) Chemurg. Pap. 1946 Ser. 4: 473-473.3.

The author discusses the existing water resources of South Carolina as these have been modified by past land-use. Future enhancement of water resources will depend on public interest and intelligent cooperation of landowners.

(95) _____
1946. Watershed management - 1931--1946. USDA Forest Serv. Southeast. Forest Exp. Stn. Anniv. Rep. 1921-1946: 43-50.

This is a progress report of the activities at Coweeta Hydrologic Laboratory and Copper Basin from 1931 to 1946.

(96) _____
1946. Where little waters write big stories. Am. Forests 52: 574-577, 603.

The author describes watershed experiments underway at the Coweeta Hydrologic Laboratory and discusses what has been learned about water yield and erosion from studies of complete removal of forests, of clearing and cultivating steep forest lands, and of woodland grazing.

(97) _____
1947. Water resource management. N.C. Eng. 3(2): 9-12, 40.

This article is a general summary on the research facilities, program, and findings at the Coweeta Hydrologic Laboratory.

(98) _____
1947. Watershed experiments conducted in giant outdoor laboratory. Timber Top. 10(4): 2-4, 9.

The author reviews the objective of watershed research at the Coweeta Hydrologic Laboratory and discusses the effects on water yield of clearing and cultivating steep forest lands, of complete removal of forest trees, of woodland grazing, and of logging and burning watersheds.

(99) Hursh, C. R.
1948. Local climate in the Copper Basin of Tennessee as modified by the removal of vegetation. U. S. Dep. Agric. Circ. 774, 38 pp.

Meteorological records were collected from three contiguous land areas that once supported a uniform hardwood forest but are now characterized by three distinct vegetative conditions: forest, grass, and bare soil. Differences in air and soil temperatures, wind, evaporation, moisture saturation deficit of the air, and rainfall indicate that each vegetative zone possesses a distinctive local climate.

(100) _____
1949. Climatic factors controlling roadside design and development. Highw. Res. Board, Natl. Res. Counc. Mag., pp. 9-19.

Factors which influence the revegetation of roadbanks--drying by wind, soil temperatures, frost action, mulching, and road design--are discussed.

(101) _____
1951. Research in forest-streamflow relations. Unasylva 5: 2-9.

The objectives of the research program at the Coweeta Hydrologic Laboratory are defined, and current watershed studies are described. The practical significance of research findings in the management of watershed resources is discussed.

(102) _____
1951. Watershed aspects of the New York water supply problems. J. For. 49: 442-444.

Watershed aspects of New York's problems with water supply from the Croton and Catskill systems are discussed. Past practices in forest conservation have contributed to the development and protection of these systems. However, complete closure is not synonymous with watershed management; vegetative management is often a direct means of improving soil and increasing water resource values. Watershed problems which merit further consideration are listed by priority.

(103) _____
1952. Forest management in East Africa in relation to local climate, water and soil resources. East Afr. Agric. Organ. Annu. Rep. 1952: 26-35.

As a Fulbright Research Scholar, the author presents his views on East Africa's need for expansion of farm forestry, improvement of damaged local climate, management of grazed areas, and catchment management and research.

(104) _____
1952. Now is the time. Farmers Fed. News 32(7): 12.

Owners of idle land are urged to initiate conservation measures. The value of trees for protection against erosion, stream sedimentation, and local floods is emphasized.

(105) Hursh, C. R.
1952. Water from the family spring. Living Wilderness 16(39): 11-12.

The part a spring plays in rural family life is described.

(106) _____ and Barrett, L. I.
1931. Forests of Georgia highlands, their importance for watershed protection, recreation and wood production. Ga. Forest Serv. Bull. 15, 32 pp.

The results of an early investigation of the value of Georgia's mountain forests with respect to timber production, watershed protection, and recreation use are presented.

(107) _____ and Brater, E. F.
1941. Separating storm-hydrographs from small drainage-areas into surface- and subsurface-flow. Am. Geophys. Union Trans., Part III: 863-871.

This classic study of hydrographs from streams and ground-water wells demonstrates that hydrographs from forested catchments at Coweeta are comprised of channel precipitation and various subsurface flow components rather than overland flow. In accounting for the stormflow volume, the authors describe five sources of stormwater. They also describe the process which became known 20 years later as the concept of variable source area.

(108) _____ and Connaughton, C. A.
1938. Effects of forests upon local climate. J. For. 36: 864-866.

Early studies of the effects of forests on climate as authorized in the United States under the McSweeney-McNary Forest Research Act of 1928 are described. Indications are that forests exert little influence on climate of large areas but have a marked effect on local or environmental climate. Observations were made at Copper Basin, a 7,000-acre area completely denuded by smelter fumes, and in the adjacent hardwood forest. The information obtained on microclimate has application in studies of fire, shelter-belts, forest management, and watershed management.

(109) _____ and Craddock, G. W.
1949. Review on book "Hydrology" by C. O. Wisler and E. F. Brater. J. For. 47: 844-845.

As the citation indicates.

(110) _____ and Crafton, W. M.
1935. Plant indicators of soil conditions on recently abandoned fields. USDA Forest Serv. Appalachian Forest Exp. Stn. Tech. Note 17, 3 pp.

Growing conditions on abandoned farm fields to be reforested are indicated by the species of plants present. Plant indicators which serve as guides in the selection of tree species and planting methods are given for four grades of sites, as determined by the amounts of soil moisture and nutrients present. Plant succession on each of these sites is discussed.

(111) Hursh, C. R., and Fletcher, P. W.
1943. The soil profile as a natural reservoir. Soil Sci. Soc. Am. Proc. 7: 480-486.

A 7-acre watershed was intensively instrumented with ground-water wells to test the concept that the soil profile has a measurable storage capacity and a regulating effect on ground-water discharge. Well elevations were correlated with measured discharge so that aquifer dimensions and porosity required for detention storage could be estimated. Three types of reservoir functions of the soil profile were recognized.

(112) _____ and Haasis, F. W.
1931. Effects of 1925 summer drought on Southern Appalachian hardwoods. Ecology 12: 380-386.

Total rainfall recorded at Asheville, North Carolina, from May to August 1925 was 5.11 inches, whereas the normal is 15.97 inches. Trees on ridges and upper slopes between 2,100 and 2,600 feet elevation became wholly or partially brown during August and September, and some species (chiefly oaks and shortleaf and pitch pines) experienced premature leaf fall. Leaf browning and early fall were more pronounced on younger trees and were particularly severe on dogwood, sourwood, and chestnut. Chestnut oaks and pine survived on areas where black oaks were completely killed.

(113) _____ and Hoover, M. D.
1942. Naturalized roadbanks. Better Roads 12(6): 13-15, 24-25; 12(7): 17-20.

Naturalization and stabilization of roadbanks by vegetation are discussed as part of road construction. Experiments begun in 1934 at the Appalachian Forest Experiment Station indicate that seeding, planting, fertilizing, and mulching are practical methods of stabilizing banks.

(114) _____ and Hoover, M. D.
1942. Soil profile characteristics pertinent to hydrologic studies in the southern Appalachians. Soil Sci. Soc. Am. Proc. 6: 414-422.

The two most essential profile characteristics in hydrologic studies--retention and detention storage--are functions of soil porosity, water-storage opportunity, and transmission rate of water. Detention storage is measured as noncapillary porosity. Retention storage is measured in terms of additional water of specific retention needed to satisfy capillary requirements. The characteristics of pore space in the soil mass can be easily determined by utilizing the principle of water displacement of air from undisturbed volume samples.

(115) Hursh, C. R., Hoover, M. D., and Fletcher, P. W.
1942. Studies in the balanced water-economy of experimental drainage-areas. Am. Geophys. Union Trans., Part II: 509-517.

In this intensive study of the water balance, estimates of precipitation, ground-water and surface-water flow, and evapotranspiration are the factors used to account for water circulating through a watershed system.

(116) _____ and Lieberman, J. A.
1946. Watershed management in the Southeastern States. USDA Forest Serv. Southeast. Forest Exp. Stn., 7 pp.

Knowledge gained at Coweeta from cutting forest stands, unrestricted logging, mountain farming, and woodland grazing is related to good watershed management in the Southeast.

(117) _____ and Pereira, H. C.
1953. Field moisture balance in the Shimba Hills, Kenya. East Afr. Agric. J. 18(4): 1-7.

This article draws on limited observations and field measurements to reconstruct and compare the moisture balance of the grass-covered and depleted Shimba Hills of Kenya with that under a natural forest. The natural forest, which once occupied the Shimba Hills, is a more desirable cover than grass for maximum-sustained water yield because water additions from mist and dew are greater from the forest.

(118) Johnson, E. A.
1949. Watershed studies producing valuable information. Outdoor News Bull. 3(11): 4.

Research at Coweeta to determine the influence of management practices on streamflow is briefly discussed.

(119) _____
1952. Effect of farm woodland grazing on watershed values in the southern Appalachian Mountains. J. For. 50: 109-113.

The effects of 11 years of grazing cattle on a forested Appalachian watershed are reported. The experiment is described; the effects of grazing on vegetation, soil, and water are presented; and practical implications of grazing mountain watersheds are discussed.

(120) _____ and Dils, R. E.
1956. Outline for compiling precipitation, runoff, and ground water data from small watersheds. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 68, 40 pp.

Procedures used at the Coweeta Hydrologic Laboratory for systematic compilation of data for continuous records of precipitation and stream discharges are described.

(121) _____ and Kovner, J. L.
1954. Increasing water yield by cutting forest vegetation. Ga. Miner. Newsl. 7(4): 145-148.

The authors report on changes in water yield at Coweeta after several different forest treatments.

(122) Johnson, E. A., and Kovner, J. L.
1956. Effect on streamflow of cutting a forest understory. Forest Sci. 2: 82-91.

On Coweeta Watershed 19, the laurel and rhododendron understory (22 percent of total basal area) was cut between December 1948 and March 1949. A 4-inch increase in water yield was achieved the first year after treatment, and the yield increase declined during the next 6 years. This increase was almost evenly divided between the growing and dormant seasons.

(123) _____ and Meginnis, H. G.
1960. Effect of altering forest vegetation on low flows of streams. Comm. Surf. Waters, Gen. Assem. Helsinki. Int. Assoc. Sci. Hydrol. Publ. 51: 257-266.

Large increases in low flows were recorded after mountain hardwood stands were cut on controlled watersheds in North Carolina, and appreciable decreases in flow were recorded after pines were planted on a small Ohio watershed.

(124) Jones, LeRoy
1955. A watershed study in putting a hardwood forest at the Coweeta Hydrologic Laboratory in the southern Appalachian Mountains under intensive management. M.F. Grad. Probl., Univ. Ga. George Foster Peabody Sch. For., 43 pp.

Conversion of a forested catchment at Coweeta from light to intensive management involving single-tree selection, proper road location and construction, and proper logging methods is described. Little increase in stream turbidity was observed. Recommendations for future management are given.

(125) Katana, M. S.
1955. Some comparisons of precipitation, streamflow, and soil on a denuded, a grass-covered, and a forested watershed in the Copper Basin of Tennessee. M.F. Thesis, N.C. State Coll., 124 pp.

Comparison of a denuded, a grass-covered, and a forested watershed at Copper Basin revealed that rainfall was highest on the forested and lowest on the denuded watershed, whereas annual streamflow was highest from the denuded and lowest from the grassed watershed. During the dormant season, flow was highest from the forested and lowest from the grassed watershed. Maximum peak discharge was greatest from the denuded (2,700 c.s.m.), intermediate from the grassed (2,200 c.s.m.), and lowest from the forested watershed (100 c.s.m.). Soils on the three experimental areas did not differ in acidity, calcium, or potassium; but organic matter and phosphorus were lowest on the denuded watershed.

(126) Klawitter, R. A.
1962. Silvics and the wetland forest. Appalachian Sect. Soc. Am. For. Proc., pp. 8-9.

The author discusses the silvical research underway at each of the wetland forest sites at the Charleston Research Center.

(127) Klawitter, R. A.
1965. Woodland drainage in the Southeast. J. Soil & Water Conserv. 20: 181-182.

A brief account is given of woodland drainage practices in the Southeast and their use in altering wet forest sites.

(128) _____
1965. Woodland water management in soil and water conservation. 9th Annu. Meet. Ga. Chapter Soil Conserv. Soc. Am. Proc., 9 pp.

Water management is a reality on about 2 million acres of wetland forest in the coastal plain. Practices must be tailored to fit particular kinds of forests, trees, and soils in the wetlands. Practices must be controlled and well enough understood to enable changes from the production of one forest resource to another, singly or in combination, as the future demands.

(129) _____
1966. Diameter growth of mature loblolly pine unaffected by under-story control. South. Lumberman 213(2656): 154-155.

Diameter growth of 60-year-old loblolly pine on plots where the under-story had been eradicated by prescribed summer fires and growth of similar trees where the under-story was untreated were not meaningfully different. Adequate rainfall during the growing season and advanced age of the trees could explain the study results.

(130) _____
1966. Drainage. 1966 Symp. Hardwoods Piedmont & Coastal Plain Proc., Ga. Forest Res. Counc., Macon, pp. 16-17.

Drainage of wet hardwood lands is a problem because water controls the establishment of hardwoods and their subsequent growth rates.

(131) _____
1966. Early response of pole-sized slash pine to drainage. Southeast. Forest Exp. Stn., U. S. Forest Serv. Res. Note SE-63, 2 pp.

Early results from a drainage study on the Apalachicola National Forest indicate height growth of pole-sized slash pine may improve considerably within a few days after sandy, wet pine flats are ditched.

(132) _____
1967. Water management in coastal plain woodlands. South. Lumberman 215(2680): 175-177.

Water management is a reality on many acres of wet woodlands in the coastal plain. Man has shown he can shape wetland forest environments to meet his future needs for any of several natural resources by prescribed changes in water regimes, soil properties, and forest vegetation. However, since needs change with time, perhaps the measures we apply to wetland forests should be sufficiently controlled and well enough understood to enable us to change from the production of one forest resource to another as the future demands.

(133) Klawitter, R. A.
1968. Soils information used and needed for woodland production: research findings--organic soils. South. Reg. Tech. Work-Plann. Conf. Coop. Soil Surv. Proc., Clemson Univ., Clemson, S. C., 7 pp.

Large acreages of organic soils in the South are available for woodland production, but landowners need information on these soils to aid in site selection. Criteria that should be included in future surveys of organic soils include botanical origin, stratigraphy, depth, degree of decomposition, wood content, acidity, water sources, and water conductivity. In addition, information is needed on subsoil material, natural vegetation, and fertility.

(134) _____
1969. Wind damages improperly planted slash pine. South Lumberman 218(2709): 24.

The problem of leaning in 2-year-old slash pine was studied on the Apalachicola National Forest. The causes were identified as improper planting, wet soil, and wind.

(135) _____
1970. Does bedding promote pine survival and growth on ditched wet sands? Northeast. Forest Exp. Stn., USDA Forest Serv. Res. Note NE-109, 4 pp.

Results from a study of prepared beds for planting slash pine on a wet, sandy flat in Florida were inconclusive. Early growth was improved, but survival was not. Differences between a bedded site and an unbedded site were slight.

(136) _____
1970. Small watershed program--the forest research assessment. Natl. Watershed Congr. Proc. 17: 161-165.

Research to determine the impact of watershed programs authorized by Public Law 566 on the total environment of swamps and bottom lands has been inadequate. A highly intensified research program to develop water management systems that will enhance wetland forest environments and, at the same time, achieve the necessary watershed objectives of both the general public and the local landowners is long overdue.

(137) _____
1970. Water regulation on forest land. J. For. 68: 338-342.

Key objectives of water regulation on wet forest land are to increase timber production and to improve wildlife habitat, range land, and flood control. Each kind of wetland forest--swamps, bottom lands, bays, and wet flats--must receive a prescription suited to local peculiarities, because water regulation works best when properly applied to the task for which it is designed. Measures applied, however, must be well enough understood and sufficiently controlled to enable changes in design and shifts in productivity from one resource use to another as the future demands.

(138) Klawitter, R. A., Stubbs, Jack, and Johnson, F. M.
1963. Tests of Arasan 75-Endrin 50W rodent repellent on Shumard and swamp chestnut oak acorns. Southeast. Forest Exp. Stn., U. S. Forest Serv. Res. Note SE-4, 2 pp.

Arasan 75-Endrin 50W® is an effective rodent repellent only when alternate food supplies are readily available.

(139) _____ and Young, C. E., Jr.
1965. Forest drainage research in the coastal plain. J. Irrig. & Drain. Div., ASCE, 91(IR3) Proc. Pap. 4456: 1-7.

Preliminary information is presented on expected increases in productivity of drained wetland forest soils. Results are based on a study in northwest Florida and a survey in coastal North Carolina. Increases in soil productivity were evaluated in terms of height and volume growth of pine trees.

(140) Knipling, E. B.
1963. Investigation of the Schardakow Method for the measurement of diffusion pressure deficit. M.S. Thesis, Duke Univ. Sch. Bot., 72 pp.

Improvement of a simple method for measuring the water potential in leaves is described, and the relationship between water potential and water deficit in dogwood and sourwood is shown.

(141) _____
1967. Effect of leaf aging on water deficit-water potential relationships of dogwood leaves growing in two environments. Physiol. Plant. 20: 65-72.

The relationships between water deficit and water potential were not the same for dogwood leaves of different ages or for leaves of the same age but growing in different environments. With leaf aging, particularly under high light intensity and dry environmental conditions, the relationships shifted to progressively lower water potentials for a given water deficit, increased dry weight, decreased cell-wall elasticity, and decreased osmotic potentials. The lack of constancy in the relationships reduces the usefulness of water deficit or relative turgidity as an estimator of water potential.

(142) _____
1967. Measurement of leaf water potential by the dye method. Ecology 48: 1038-1041.

The dye method for measuring leaf water potential is simple, inexpensive, and suitable for both laboratory and field work. Leaves are immersed in a graded series of solutions, and the solution which neither gains nor loses water is assumed to have a water potential equal to that of the leaf.

(143) Knipling, E. B., and Kramer, P. J.
1967. Comparison of the dye method with the thermocouple psychrometer for measuring leaf water potentials. Plant Physiol. 42: 1315-1320.

The dye method for measuring water potential was compared with the thermocouple psychrometer method and found to be useful for measuring leaf water potentials of forest trees and common laboratory plants.

(144) Kovner, J. L.
1955. Changes in streamflow and vegetation characteristics of a southern Appalachian Mountain watershed brought about by a forest cutting and subsequent natural regrowth. Ph. D. Thesis, State Univ. N. Y. Coll. For., Syracuse, 245 pp.

The first year after a 40-acre watershed at Coweeta was clearcut, water yield increased 15.11 inches; this increase declined as the coppice stand regrew. A multiple regression showed a highly significant correlation between seasonal increases in streamflow and time. It was estimated that increases would be less than 2 inches in 25 years and negligible in 40 years. Increases did not appear related to amount of precipitation during May-Sept. and Oct.-Dec. but were related to precipitation in the Jan.-April period. By the 12th year after cutting, basal area had increased to 51.6 square feet per acre, about half of the basal area of a projected normal stand, but total annual production of foliage did not differ significantly between treated and control areas.

(145) _____
1957. Evapotranspiration and water yields following forest cutting and natural regrowth. Soc. Am. For. Proc. 1956: 106-110.

The effects on stream regimen of cutting and later regrowth of a hardwood forest in the southern Appalachians are reported. Changes in stand density are compared with changes in streamflow and P - RO (precipitation minus runoff).

(146) _____
1957. Evapotranspiration in forest stands of the southern Appalachian Mountains. Bull. Ga. Acad. Sci. 15(3): 80-85.

The author presents a method of estimating evapotranspiration by the water balance equation P - Ro = Ev, where P = precipitation, Ro = streamflow, and Ev = evapotranspiration, and discusses the relationship between estimated evapotranspiration and elevation.

(147) _____ and Evans, T. C.
1954. A method for determining the minimum duration of watershed experiments. Am. Geophys. Union Trans. 35: 608-612.

A simple graphic solution is described for approximating the length of time required to detect significant differences between treatments on experimental watersheds.

(148) Lieberman, J. A.
1947. Water resource and watershed management research in the Southeast. Am. Waterworks Assoc. J. 39(5): 443-454.

The facilities, research program, and research findings at Coweeta Hydrologic Laboratory are reviewed.

(149) _____ and Fletcher, P. W.
1947. Further studies of the balanced water cycle on experimental watersheds. Am. Geophys. Union Trans. 28: 421-424.

Maintaining a chronological account or balance of the components of the water resource on a watershed is frequently valuable in hydrology studies. In this paper, a time period for studying this balance is described: the period between the times of maximum watershed storage at the end of each dormant season. Changes in ground-water storage are thus taken into account, and, by choosing the beginning and ending points of the year at times of field capacity, changes in water storage in the soil mass are minimized.

(150) _____ and Hoover, M. D.
1948. The effect of uncontrolled logging on stream turbidity. Water & Sewage Works 95(7): 255-258.

The effects of the unrestricted logging of Watershed 10 at Coweeta on soil erosion and stream turbidity are reported. The authors stress the need for improvements in the design, location, and maintenance of roads and in logging methods.

(151) _____ and Hoover, M. D.
1948. Protecting quality of stream flow by better logging. South. Lumberman 177(2225): 236-240.

The authors report on the results of unrestricted logging on Watershed 10 at Coweeta and present suggestions for road location and maintenance and logging practices which will protect the soil and water resource.

(152) _____ and Hoover, M. D.
1951. Stream-flow frequency changes on Coweeta experimental watersheds. Am. Geophys. Union Trans. 32: 73-76.

Frequency distribution curves of mean daily discharge from treated and control watersheds at Coweeta are compared for the prior- and post-treatment periods. Conclusions are drawn about the effect of the treatments on the regimen of daily stream-flow and about the practicability of using frequency distribution curves to show stream-flow changes brought about by experimental land-use treatments.

(153) Meginnis, H. G.
1956. Forestry and water resource development in the South. Forest Farmer 16(2): 12-13, 28, 30-32.

This paper discusses four prospective developments which, because of their effect on water supply, will affect southern forestry in the years ahead. The developments are intensive development and use of valley lands, construction of impoundments to store and regulate streamflow, growing industrial demands for water, and public efforts to clean up streams and combat pollution.

(154) Meginnis, H. G.
1956. Principles of watershed management based on current research. Watershed Manage., Interstate Comm. Potomac River Basin, pp. 15-19.

Watershed management as the integrated management of all renewable resources of a drainage basin is discussed. Principles of watershed management based on current research are recounted, premises that underlie and further define watershed management are outlined, and some important research needs are listed.

(155) _____
1959. Increasing water yields by cutting forest vegetation. Symp. Hannoversch-Münden. Int. Assoc. Sci. Hydrol. Publ. 48: 59-68.

The author discusses volume and timing of yield increases produced by clearcutting with annual cutting of regrowth, clearcutting with coppice regrowth allowed, and clearcutting of understory vegetation. Despite indications afforded by these experiments, a more complete knowledge of water requirements of cover and of plant-soil-climatic factors which govern evapotranspiration is required before yield increases caused by cover manipulations can be predicted accurately.

(156) _____
1960. Watershed management research--challenging career for young scientists. Ames For. 47: 20-24.

The author outlines present knowledge in the field of watershed management, needs for further research, and opportunities for specialists in many disciplines who might wish to enter this field.

(157) Merrick, E. T., and Johnson, E. A.
1952. Mountain water. Am. Forests 58(10): 30-32, 38.

Objectives of the research program at Coweeta and studies of stream temperature and interception are briefly discussed.

(158) Metz, L. J.
1952. Calcium content of hardwood litter four times that from pine; nitrogen double. USDA Forest Serv. Southeast. Forest Exp. Stn. Res. Notes 14, 2 pp.

Hardwood litter returned greater amounts of calcium and nitrogen to the soil than did pine litter.

(159) _____
1952. Weight and nitrogen and calcium content of the annual litter fall of forests in the South Carolina Piedmont. Soil Sci. Soc. Am. Proc. 16: 38-41.

Weight of leaves, twigs, bark, and fruit fall is presented for pine, pine-hardwood, and hardwood stands. Leaf fall ranged from 2,900 pounds per acre in a 30- to 40-year-old shortleaf stand to 4,500 pounds per acre in a 25-year-old loblolly pine plantation. Leaf fall for hardwood stands ranged from 3,600 to 4,100 pounds per acre. Hardwoods returned twice as much nitrogen, three times as much magnesium, and five times as much calcium to the soils as did pine stands.

(160) Metz, L. J.
1954. Forest floor in the Piedmont region of South Carolina. Soil Sci. Soc. Am. Proc. 18: 335-338.

The annual litter fall, weight of the forest floor, and incorporation of organic matter in the surface foot of mineral soil are reported for three pine, three pine-hardwood, and three hardwood stands in the South Carolina Piedmont. The forest floors are classified as to humus type, and some practical applications of the information to forest management are discussed.

(161) _____
1958. The Calhoun Experimental Forest. USDA Forest Serv. Southeast. Forest Exp. Stn., 24 pp.

The research program at the Calhoun Experimental Forest is discussed, with emphasis on problems concerning forests, soils, and water.

(162) _____
1958. Moisture held in pine litter. J. For. 56: 36.

Litter under a 12-year-old plantation of pine in the Piedmont held a maximum of 0.09 inch of moisture and a minimum of 0.01 inch. Drying rapidly removed moisture so that equilibrium moisture conditions were reached 11 days after a rain.

(163) _____
1959. The description and measurement of the forest floor. Tech. & Methods Meas. Understory Veg. Symp. Proc. 1958: 105-113. Publ. jointly by USDA Forest Serv. South. Forest Exp. Stn. and Southeast. Forest Exp. Stn.

Nomenclature of the forest floor is discussed, and methods of measuring components and characteristics of the forest floor are described.

(164) _____
1960. The de la Howe old-growth forest in Piedmont shortleaf pine. J. For. 58: 807-809.

The author describes the history and condition of the de la Howe forest and emphasizes the value of such bench marks for study of soil-plant relations, forest-disease impacts, and forest growth potential.

(165) _____
1960. Hydrologic properties of southern forest soils. South. Forest Soils. La. State Univ. Sch. For., 8th Annu. For. Symp. Proc. 1959: 19-24.

Soil properties which affect movement and storage of water are discussed, and the importance of maintaining favorable hydrologic properties is stressed.

(166) Metz, L. J., and Douglass, J. E.
1959. Soil moisture depletion under several Piedmont cover types. U. S. Dep. Agric. Tech. Bull. 1207, 23 pp.

Data are presented on soil moisture regimen under pine and pine-hardwood forest cover, old-field (broomsedge) vegetation, and bare soil. Forest types depleted soils to 66 inches at about the same rate, regardless of species, whereas moisture loss from broomsedge grass and bare plots was limited to the surface 30 inches. The pattern of withdrawal and recharge of soil moisture is cyclic; recharge begins in the late fall or winter and depletion begins with the start of the growing season. Moisture loss from barren and vegetated soils is related to depth; with increasing depth, the rate of moisture loss decreases.

(167) _____ Lotti, Thomas, and Klawitter, R. A.
1961. Some effects of prescribed burning on coastal plain forest soil. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 133, 10 pp.

From 1946 to 1956, a study was made of the effect of prescribed burning on soil beneath loblolly pine stands growing in the lower coastal plain of the Southeast. Annual and periodic fires for the 10-year period had no significant influence on physical properties of the soil. However, mineral elements, nitrogen, and organic matter tended to increase in the surface 4 inches of burned plots.

(168) Munns, E. N.
1947. Forest hydrology in the Appalachians. J. Soil & Water Conserv. 2: 71-76.

The author discusses the beneficial effects of the forest on regulating streamflow, as opposed to other forms of land management, and also gives a general discussion of watershed experiments at the Coweeta Hydrologic Laboratory.

(169) _____
1948. Our forests and watersheds. Sci. Mon. 67(5): 347-354.

The research facilities, program, and findings at Coweeta Hydrologic Laboratory are summarized.

(170) Murphy, C. E., Jr.
1970. Energy sources for the evaporation of precipitation intercepted by tree canopies. Ph. D. Diss., Duke Univ., 260 pp.

The total energy balance of individual tree leaves was measured in a controlled environment chamber and simulated for a wide range of conditions on a digital computer. This study demonstrated the use of existing engineering theory and parameters for estimating leaf energy exchanges. Water loss from an externally wet leaf was always greater than from an unwet transpiring leaf because the cool evaporating surface could absorb extra heat from the air and because a given amount of energy was more efficient in evaporating surface water than transpired water. Evaporation was shown to occur during precipitation. This evaporation rate can account for only part of the slope of the interception equation derived at Coweeta for eastern hardwood stands.

(171) Nelson, T. C.
1955. Chestnut replacement in the southern highlands. Ecology 36: 352-353.

Seventeen 1/5-acre plots were established in 1934 prior to the onset of chestnut blight and were resurveyed in 1941 and 1953. Chestnut decreased from 41 to 1 percent of total basal area from 1934 to 1953. Basal area of yellow-poplar, black oak, and scarlet oak increased while other species remained approximately the same or decreased. Invasion of openings was primarily by sourwood, cucumber magnolia, sweet birch, and eastern hemlock.

(172) _____ and Johnson, E. A.
1954. Applying unit area control to watershed management. J. For. 52: 130.

The authors outline the potential application of unit area control to a watershed for integrated management of timber and water resources.

(173) Olson, D. F., Jr., and Hoover, M. D.
1954. Methods of soil moisture determination under field conditions. USDA Forest Serv. Southeast. Forest Exp. Stn. Pap. 38, 28 pp.

Field methods of determining soil moisture are discussed in detail.

(174) Patric, J. H.
1963. Forest experiment demonstration area on trail. Appalachian Trailway News 24(2): 21.

A new experiment in multiple use management at Coweeta is visible to hikers on the Appalachian Trail.

(175) _____ Douglass, J. E., and Hewlett, J. D.
1965. Soil water absorption by mountain and piedmont forests. Soil Sci. Soc. Am. Proc. 29: 303-308.

In the southern Appalachians and the South Carolina Piedmont, absorption of soil water by tree roots in the top 20 feet of soil was determined from moisture and matric potential measurements under 50- by 50-foot, plastic-covered plots. The data indicate that, where soil matric potential is kept low by frequent rainfall, most transpired water comes from densely rooted surface soil, whereas soil water well beyond rooting depths returns to the surface during long periods without rain.

(176) Pitcher, K. A.
1955. The influence of cove-site vegetation on streamflow and soil moisture in the southern Appalachians. M.F. Thesis, N.C. State Coll., 99 pp.

Cove-site vegetation was killed on one watershed, while another forested watershed was retained as a control. Soil characteristics, precipitation, streamflow, stream temperature, and soil moisture were measured on each catchment. Stream temperatures were significantly increased by the treatment. In the treated cove, moisture content in the 5-foot soil depth was 3.5 inches greater than in the untreated cove. Differences in moisture content became apparent around the first of July and increased through August.

(177) Schreuder, H. T., and Swank, W. T.
1971. A comparison of several statistical models in forest biomass and surface area estimation, pp. 123-136. In Forest biomass studies. Univ. Maine, Life Sci. & Agric. Exp. Stn., Misc. Publ. 132.

The squared correlation and log likelihood techniques are discussed and used to evaluate statistical estimation models for eastern white pine biomass and surface area data. Three a priori linear models are considered: (1) an unweighted untransformed model, (2) a weighted untransformed model, and (3) a log-log transformation model.

(178) Sluder, E. R.
1958. Mountain farm woodland grazing doesn't pay. USDA Forest Serv. Southeast. Forest Exp. Stn. Res. Notes 119, 2 pp.

The general results of the mountain farm experiment at Coweeta are presented.

(179) Smalley, G. W.
1956. Some criteria for determining unit area control in watershed management on municipal and industrial watersheds in the southern Appalachians. M.S. Thesis, Mich. State Univ. Agric. & Appl. Sci., 99 pp.

The results of applying unit area control to integrated management of water and timber resources at Coweeta are presented. Unit areas delineated on the basis of aspect, slope, soil depth, and vegetation were applied on a small-unit watershed to determine practicality of the approach. Unit area control provides a satisfactory approach to integrated management of timber and water if both hydrologic and silvicultural characteristics are considered, but knowledge of the interrelationships between plants, soil, and water is essential before management practices can be prescribed for unit areas.

(180) Snyder, J. E., and Hursh, C. R.
1938. Low cost erosion control on highway slopes in Southeastern United States. Highw. Res. Board Proc., Part 1: 213-215.

Important factors in stabilizing exposed highway slopes are the stability, moisture, and fertility of the soil. Steepness and length of slope, alternation of freezing and thawing, and the physical nature of soil affect soil stability. Lack of moisture because of over-drainage and direct exposure to solar radiation is also a basic cause of failure in roadside naturalization. Many road cuts expose infertile subsoil and parent-soil material which are difficult to vegetate. Use of mulches of local organic materials is a suitable means for ameliorating unfavorable site conditions.

(181) Southeastern Forest Experiment Station
1948. Watershed management research--Coweeta Experimental Forest. USDA Forest Serv. Southeast. Forest Exp. Stn., 45 pp.

This is the first guidebook to Coweeta and is designed to acquaint the reader with the laboratory, the research methods, program, findings, and future research plans.

(182) Southeastern Forest Experiment Station
1964. Improvements at Coweeta. USDA Forest Serv. Southeast. Forest Exp. Stn., 16 pp.

This report covers improvements and research at Coweeta since October 1962, when the accelerated Public Works program began at the Laboratory. Improvements consisted of construction of a road and bridge in the administration area, a 20,000-gallon gravity water system, a three-bedroom dwelling for forest superintendents, a 40- by 60-foot metal warehouse for storage, a 40- by 100-foot wet lab, and an extension to the existing office building, as well as repairs made on 18 weirs and the reworking of 25 miles of neglected roads and trails. Research activities included installation of a 356-acre multiple-use watershed and clearcutting of two forested watersheds to determine the effects of such cutting on water yield.

(183) _____
1968. Visitor's guide - Coweeta Hydrologic Laboratory. USDA Forest Serv. Southeast. Forest Exp. Stn. [In-Serv. leafl.]

This leaflet enables the reader to make a self-guided tour of the Coweeta Hydrologic Laboratory.

(184) Striffler, W. D.
1957. The soil moisture regime under native hardwoods at five elevations in the southern Appalachians. M.F. Thesis, Univ. Mich. Sch. Nat. Resour., 93 pp.

At ridgetop sites at five different elevations, data were collected for 1 year on timber stand and basal area, crown densities, litter weights and types, soil moisture, soil type and physical properties, and root densities. Results indicate that, within certain horizons, soil moisture depletion rates vary with elevation, but average depletion rates for the entire profile and total water losses do not vary with elevation.

(185) Stubbs, Jack
1962. Wetland forests. Forest Farmer 21(11): 6-7, 10-13.

Opportunities and problems of managing wetland forests in the Atlantic Coastal Plain are discussed.

(186) Swank, W. T.
1968. The influence of rainfall interception on streamflow. Hydrol. Water Resour. Manage. Conf. Proc. Clemson Univ. Water Resour. Res. Inst. Rep. 4, pp. 101-112.

The data presented provide evidence that interception loss is a major hydrologic process which reduces the quantity and alters the timing of streamflow from watersheds in the southern Appalachians when cover types are changed from mature mixed hardwoods to eastern white pine. Differences in interception loss between loblolly pine and mature hardwoods in the Piedmont of South Carolina are discussed.

(187) Swank, W. T., and Helvey, J. D.
1970. Reduction of streamflow increases following regrowth of clearcut hardwood forests, pp. 346-360. In Symposium on the results of research on representative and experimental basins. UNESCO-AIHS Publ. [Assoc. Int. Hydrol. Sci.] 96.

The mature hardwood forest on a 16-hectare catchment at the Coweeta Hydrologic Laboratory was initially clearcut in 1939. The first year following cutting, streamflow increased 360 mm. As the even-aged coppice stand regrew, annual streamflow increases approached pretreatment levels as a linear function of the logarithm of time. The watershed was clearcut again in 1962, and streamflow response for the year following cutting was 380 mm. In striking contrast to the first cutting, streamflow increases have diminished at a much faster rate, and it appears that annual water yield will return to pretreatment levels after just 16 years of forest regrowth following the second cutting. The difference in the measured response is attributed primarily to a more rapid recovery of vegetation in the second treatment period.

(188) _____ and Miner, N. H.
1968. Conversion of hardwood-covered watersheds to white pine reduces water yield. Water Resour. Res. 4: 947-954.

Mixed mature hardwoods were cleared from two experimental watersheds in the southern Appalachians, and the areas were planted with eastern white pine in 1956-57. Once the pine crowns began to close, streamflow steadily declined at a rate of 1 to 2 inches per year. By 1967, water yield from a 10-year-old pine stand on a south-facing watershed was 3.7 inches less than the expected water yield from the original hardwood forest. Most of the reduction in water-yield occurred during the dormant season and was attributed mainly to greater interception loss from white pine than from hardwoods. Because interception differences increase as white pine matures, an even greater reduction in streamflow is expected.

(189) Swift, L. W., Jr.
1960. The effect of mountain topography upon solar energy theoretically available for evapotranspiration. M.S. Thesis, N.C. State Coll., 76 pp.

A study was made to determine why results from formulas for estimating evapotranspiration losses do not agree with hydrologic measurements made on small watersheds. Study of irradiation intensities on steep north- and south-facing watersheds showed that these watersheds should receive an equal amount of radiation during the growing season; during the dormant season, the south-facing catchment should receive a much greater amount of solar radiation. Although slope and aspect do affect the quantity of solar irradiation for small watersheds, corrections for energy receipt do not completely answer the problem of why hydrologic and energy balance methods of estimating evapotranspiration do not agree.

(190) Swift, L. W., Jr., and Messer, J. B.
1971. Forest cuttings raise temperatures of small streams in the southern Appalachians. J. Soil & Water Conserv. 26: 111-116.

Stream temperatures were measured during six forest-cutting treatments imposed on 23- to 70-acre watersheds in the southern Appalachian Mountains. Where forest trees and all understory vegetation were completely cut, maximum stream temperatures in summer were raised from the normal 66° F. up to 73° or more. Some extreme treatments raised temperatures over 12° above normal. Where streambank vegetation was uncut or had regrown, summer maximums were unchanged or reduced from levels found under uncut mature hardwoods. Increases in stream temperature were judged to degrade water quality and constitute thermal pollution because, after each clearcut, water temperatures exceeded optimum levels for trout habitat.

(191) Tebo, L. B., Jr.
1955. Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the southern Appalachians. Prog. Fish-Cult. 55: 64-70.

Siltation resulting from improper land-use practices is regarded as one of the most important factors contributing to a reduction in the acreage of desirable fishing waters. This report presents quantitative data regarding the effect of siltation on bottom fauna of trout streams in the southern Appalachians.

(192) Trousdell, K. B., and Hoover, M. D.
1955. A change in ground-water level after clearcutting of loblolly pine in the Coastal Plain. J. For. 53: 493-498.

Ground-water observation wells were dug in adjacent compartments of old-growth loblolly pine-hardwood in the Coastal Plain of North Carolina. After one compartment was clearcut, the water table rose to higher levels for the remainder of the growing season than it did beneath a selectively cut forest stand. A ground-water profile, determined from a transect of 10 temporary wells spaced at 1-chain intervals from the clearcut into a selectively cut stand, showed water tables to be highest beneath clearcut strips and lowest beneath selectively cut stands.

(193) USDA Forest Service
1953. Waters of Coweeta. Agric. Inf. Bull. 117, 22 pp.

The results of 20 years of streamflow studies at Coweeta are highlighted. Text and pictorial illustrations are borrowed from a documentary film with the same title.

(194) Waggoner, P. E., and Hewlett, J. D.
1965. Test of a transpiration inhibitor on a forested watershed. Water Resour. Res. 1: 391-396.

The glyceryl half-ester of decenylsuccinic acid (GlOSA) closes tree stomata when sprayed directly upon the undersides of leaves. At Coweeta, a 12 percent reduction in transpiration might be detected as a significant increase in streamflow. Two sprays of 50 pounds of GlOSA in water applied to 30 acres of one watershed from a helicopter produced little deposit on the undersides of leaves and no clear evidence of stomatal closure. Observed increases in streamflow were statistically insignificant.

(195) Whelan, D. E.
1957. Effects of land use on streamflow. Ala. Acad. Sci. J. 29(4): 55-60.

Present knowledge of the effects of land use and treatment on streamflow is summarized. The basic concepts of land use and ground-water hydrology are discussed in order to show how soil and vegetal cover influence the disposition of precipitation.

(196) Williams, J. G.
1954. A study of the effect of grazing upon changes in vegetation on a watershed in the Southern Appalachian Mountains. (Abstr.) J. For. 52: 867.

Growth and destruction of vegetation during grazing by cattle on a forested mountain watershed are described.

(197) _____
1954. A study of the effect of grazing upon changes in vegetation on a watershed in the southern Appalachian Mountains. M.S. Thesis, Mich. State Univ. Agric. & Appl. Sci., 138 pp.

The effect of grazing on vegetation of a 145-acre forested watershed at Coweeta is reported. For 11 years, six cattle grazed an average of 4 months each year. By the end of the first season, practically all herbaceous forage and much of the hardwood understory had been utilized. After the second season, supplemental feeding was required. The effect of grazing was particularly severe in the cove-hardwood site. Insufficient forage was present in the dense hardwood stands to make grazing profitable, and young trees of desirable species were damaged by grazing.

(198) Young, C. E., Jr.
1961. Drainage research on forest wetlands in the Southeast. La. State Univ., ARS-SCS Workshop Land Leveling for Drain. & Irrig. Proc. 1961: 87-88.

The wetland problem areas in the Southeast, current research underway, and plans for the future are briefly discussed.

(199) Young, C. E., Jr.
1964. Water management: key to wetland forest improvement in the Southeast. (Abstr.) Assoc. South. Agric. Work. Proc. 1964: 61-62.

The author discusses problems associated with managing wetland forests, preliminary research results on improving wetlands through drainage, and research activities of the Wetland Improvement Project in Charleston, South Carolina.

(200) _____
1966. Growth trends of loblolly pine on two drained wetlands. South. Lumberman 213(2656): 160-161.

Diameter and height growth of 10-year-old loblolly pines were measured for 2 years on a sandy ridge bay and a heavy clay "Carolina" bay near Charleston, South Carolina. Measurements were related to amounts of precipitation and water-table levels. Growth was better during a wet year when water-table levels were higher than during a dry year when lower water-table levels prevailed. Growth was also considerably better on the heavy soil than the light soil.

(201) _____
1966. Soil sampling small wetland forest plots in the coastal plain. Southeast. Forest Exp. Stn., U. S. Forest Serv. Res. Note SE-59, 2 pp.

The variability of soil properties creates problems in soil sampling in the lower coastal plain, where little information is available to guide study designs. This study shows the number of sampling locations on each of the test plots needed to estimate the mean of various physical properties within 5 percent for two probability levels and two common wetland soils. Scientists faced with a soil sampling problem on similar wetlands soils will now have a starting point to determine the magnitude of sampling needed in their work.

(202) _____
1966. Waterbalance on a forested watershed in the flatwoods. (Abstr.) Assoc. South. Agric. Work. Proc. 1966: 69.

Hydrologic data collected from a 400-acre watershed will be used to make short term estimations of evapotranspiration, evaluate existing groundwater and surface water supplies, and provide design criteria for water management structures.

(203) _____
1967. Streamflow--important factor in forest management. South. Lumberman 215(2680): 109-110.

Streamflow records indicate that the stormflow volume produced from a forested watershed in the lower coastal plain is highly dependent on the storage potential of the watershed prior to rainfall. On the average, this watershed produces more stormflow than forested watersheds in the mountains and Piedmont. However, streamflow is intermittent, with no-flow periods as long as 1 to 2 months occurring each year.

(204) Young, C. E., Jr.
1969. Water table, soil moisture, and oxygen diffusion relationships on two drained wetland forest sites. Soil Sci. 107: 220-222.

Statistical models that express the relationship between (1) depth to water table and soil-moisture content at 6 to 18 inches and (2) depth to water table and oxygen-diffusion rate at 12 inches have been developed for two wetland forest sites. Some of these models agreed with data published in the literature, but others did not. The coefficients of determination were reasonably high for all the relationships. The models have not been verified for other areas. The soil types sampled included Bayboro clay loam and Plummer loamy sand.

(205) _____
1970. Effect of cultural practices on water resources. Am. Soc. Civ. Eng., Soc. & Ecol. Aspects Irrig. & Drain. Spec. Conf. 1970: 77-90.

Between 1 and 2 million acres of wetland forests have been drained in the past 20 to 25 years. With today's interest in environmental degradation, facts are needed to determine whether certain cultural practices are harmful to water resources, wildlife, plant communities, and stream and estuarine biology. A study is planned on the Apalachicola National Forest in northwest Florida to obtain some of these facts. The study will run 7 to 10 years and will use the paired watershed approach for determining changes in water resources.

(206) _____ Auld, I. D., Jr., and Gaskins, Rudolph
1962. An efficient process for making wire marking pins. USDA Forest Serv. Tree Plant. Notes 53: 25-26.

A method is described which reduces manufacturing time for wire marking pins by one-half to three-quarters.

(207) _____ and Henderson, J. E.
1965. A method for sealing soil moisture access tubes. Soil Sci. 99: 213-214.

Access tubes sealed with a rubber stopper that has been secured with nails and coated with a nonhardening gasket sealer will withstand pressures up to at least 6 pounds per square inch without leaking. Necessary materials are listed, and the sealing process is described step by step.

(208) _____ and Henderson, J. E.
1966. An overflow system for a standard U. S. Weather Bureau evaporation pan. Southeast. Forest Exp. Stn., U. S. Forest Serv. Res. Note SE-60, 2 pp.

This Note describes an economical and easily installed overflow system that increased the storage capacity of a standard U. S. Weather Bureau evaporation pan by 2 inches.

(209) Young, C. E., Jr., and Klawitter, R. A.
1968. Hydrology of wetland forest watersheds. Hydrol. Water Resour. Manage. Conf. Proc. Clemson Univ. Water Resour. Res. Inst. Rep. 4, pp. 29-38.

Preliminary results from a 400-acre wetland watershed on the Santee Experimental Forest showed that average annual storm runoff was approximately twice that from forested watersheds in the Piedmont and mountains. Furthermore, during wet periods, peak runoff rates were double those computed for the watershed by an accepted drainage formula. Measured evapotranspiration was slightly greater than Thornthwaite's potential ET.

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Douglass, James E.
1972. Annotated bibliography of publications on watershed management by the Southeastern Forest Experiment Station, 1928-1970. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-93, 47 pp.

This bibliography contains annotated citations to all publications by the Southeastern Forest Experiment Station on watershed management from 1928 to 1970. Citations are indexed by subject category.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Streamflow Modification Through Management of Eastern Forests

by
James E. Douglass
and
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U.S. Department of Agriculture—Forest Service
Southeastern Forest Experiment Station
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Streamflow Modification Through Management of Eastern Forests

by

James E. Douglass, Principal Hydrologist

and

Wayne T. Swank, Principal Plant Ecologist

Coweeta Hydrologic Laboratory
Franklin, North Carolina

INTRODUCTION

Protection of the water resource was a primary objective in establishing the National Forest System in America, and improving quantity, quality, and timing of streamflow is an important objective of forest management in certain regions of the United States. Effective management of the forest for increased streamflow presupposes that impact of various management practices on water yield can be predicted, but prediction equations do not exist for most regions.

Because the difference between precipitation input and vapor loss represents the quantity of water available for man's use, the watershed manager seeks to reduce the total vapor loss from forest vegetation in order to increase the flow of streams. Estimating the evaporative loss is possible by using energy balance and water balance methods. Although promising, the energy balance method has not been developed to the point where it is a useful tool for guiding water management activities. The water balance approach derives vapor loss indirectly; its accuracy is usually limited by errors in measuring rainfall and runoff, and unmeasured leakage can be particularly troublesome.

Using paired control and treatment watersheds, the change in yield produced by vegetative changes can be precisely measured and the effect of errors minimized. If leakage occurs, the estimate of change in yield is conservative (5) and represents the minimum effect expected from similar experiments. Thus, the catchment study has been the most definitive method for describing the response of water yield to vegetative manipulation. Although many watershed treatments have been conducted,

they have generally been regarded as case studies for different soils, geology, and climate. Hibbert's (6) worldwide survey of catchment studies has been the only attempt to consolidate the results of watershed experiments. He concluded that "...results of individual treatments vary widely and for the most part are unpredictable." Consequently, little information has been available to guide management of forest lands for increased production of water.

This Paper reports on a recently devised, preliminary method for predicting water yield changes which result from cutting hardwood forests of the Appalachians. Predicted yield increases were compared with actual yield increases obtained from a logged watershed in continuing efforts to translate results from catchment studies into practical guides for managing water resources. This Paper also discusses the effects of forest cuttings on other characteristics of streamflow.

EXPERIMENTAL SITES AND WATERSHEDS

The boundary of the Appalachian Highlands Physiographic Division (10) and the four sites[1] of catchment studies are shown in figure 1. Latitudes vary from about 35 degrees to 44 degrees north and precipitation varies from more than 80 inches at Coweeta Hydrologic Laboratory in North Carolina to 48 inches at Hubbard Brook Experimental Forest in New Hampshire. Annual snowfall (not accumulation) averages about 10 inches at Coweeta, 30-40 inches at the Fernow Experimental Forest in West Virginia, 40-60 inches at the Leading Ridge watershed in Pennsylvania, and 60-80 inches at Hubbard Brook. Annual runoff is lowest (15 inches) at Leading Ridge and highest (35-60 inches) at Coweeta (14). Soils range from residual ones 20 feet or deeper at Coweeta to shallow glaciated soils averaging about 5 feet deep at Hubbard Brook. The common characteristic of all sites is a mixed deciduous hardwood forest cover, although species composition varies between sites. Timber resources in the experimental areas are typical of millions of acres of forest land in the Appalachian Highlands.

Table 1 lists the cutting experiments by location and describes features of each experiment. Of the 23 experiments, 13 were conducted at Coweeta, 8 at Fernow, and 1 each at Leading Ridge and Hubbard Brook. Treated catchments ranged in size from 22 to 356 acres, and most major topographic aspects were represented. The type of cutting depended upon study objectives; for example, treatments included cutting all vegetation over part or all of the catchment and cutting or deadening a portion of the vegetation over part or all of the catchment. Individual treatments were applied with and without removal of forest products and, in some instances, with subsequent herbicide control of regrowth.

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[1] The Coweeta Hydrologic Laboratory, Fernow Experimental Forest, and Hubbard Brook Experimental Forest are field research installations operated by the Forest Service, USDA. The Leading Ridge watershed is a field research installation operated by the School of Forest Resources, Pennsylvania State University.

We acknowledge the cooperation of W. E. Sopper, Pennsylvania State University, and R. S. Pierce and J. H. Patric, Northeastern Forest Experiment Station, for supplying data for this study.

Figure 1.--Location of the four experimental watershed study sites within the Appalachian Highlands.

PREDICTION METHOD

Results from 22 cutting experiments conducted in the Appalachian Highlands are plotted in figure 2. The ordinate is the first-year streamflow increase (the deviation of measured flow the first year after cutting from the expected flow if the vegetation had not been cut). The abscissa is the percentage reduction in forest stand basal area achieved by cutting. In a few cases, the plotted value is a nonsignificant increase judged by the calibration regression error term, but these points are plotted as the best estimate of the increase. Nonsignificant increases occurred only when cuttings removed a small percentage of the total basal area of the stand.

Streamflow response the first year after cutting is quite variable, even between catchments in the same drainage basin and for catchments having relatively similar treatments. The scatter of data results because of differences in slope and aspect of watersheds, climate, vegetative conditions, and because ordinate values are estimated from regression. Nevertheless, figure 2 leaves no doubt that substantial volumes of extra water can be produced by cutting eastern hardwood forests. Cutting part of the timber gives proportionately smaller increases, and there is a lower limit of basal area below which cutting will produce no measurable extra water. When a light partial cut is made, the residual stand may be

Table 1.--Location and description of experimental catchment studies in the Appalachian Highlands

Watershed number	Area	Aspect	Mean flow from forest	Treatment	Basal area treated (cut or deadened)	First-year water yield increase
	Acres		Inches/year		Percent	Inches
COWEETA HYDROLOGIC LABORATORY, FRANKLIN, N. C.						
1	40	S	31	Cove vegetation deadened by chemicals.	25	1.2
				All trees and shrubs cut on entire catchment, no products removed, partially burned.	100	5.8
6	22	NW	33	All trees and shrubs within zone along stream cut, no products removed.	12	0
				Hardwood forest converted to grass, then all vegetation deadened with herbicides except narrow strip alongside stream.	100	10.5
13	40	NE	34	All trees and shrubs cut on entire watershed, no products removed.	100	14.2
				Treatment repeated 23 years later.	100	15.0
17	33	NW	27	All trees and shrubs cut on entire watershed, no products removed.	100	16.3
19	70	NW	48	Laurel (Kalmia latifolia L.) and rhododendron (Rhododendron maximum L.) understory cut, no products removed.	22	2.0
22	85	N	50	All trees and shrubs within alternate 33-foot strips deadened by chemicals, no products removed.	50	6.1
[1]28	356	NE	60	All trees and shrubs cut on 190 acres, cove forest of 97 acres thinned, no cutting on remaining 69 acres; products removed.	66	6.5
37	108	NE	60	All trees and shrubs cut on entire catchment, no products removed.	100	10.2
40	50	SE	39	Commercial logging with selection cut, products removed.	22	1.7
41	71	SE	54	Commercial logging with selection cut, products removed.	35	2.7
FERNOW EXPERIMENTAL FOREST, PARSONS, W. VA.						
1	74	NE	23	Merchantable trees cut and removed on entire catchment.	85	5.1
2	38	S	26	All merchantable trees 17 inches d.b.h. and above cut and removed.	36	2.5
3	85	S	25	Selected trees above 5 inches d.b.h. cut, products removed.	14	0.3
5	90	NE	30	Selected trees above 11 inches d.b.h. cut, products removed.	22	0.7
6	54	SE	19	All trees and shrubs cut on lower half of catchment, products removed, sprouting controlled with herbicides.	51	6.5
				Remainder (49 percent of basal area) of trees and shrubs cut, products removed.	100	10.2
7	59	E	24	All trees and shrubs cut on upper half of catchment, products removed, sprouting controlled with herbicides.	49	6.1
				Remainder (51 percent of basal area) of trees and shrubs cut, products removed.	100	9.9
LEADING RIDGE, STATE COLLEGE, PA.						
2	106	SE	14	All trees and shrubs cut from 21 acres on lower portion of catchment, products removed, sprouting controlled with herbicides.	29	2.7
HUBBARD BROOK EXPERIMENTAL FOREST, WEST THORNTON, N. H.						
2	39	SE	27	All trees and shrubs cut on entire catchment, products not removed, sprouting controlled with herbicides.	100	13.5

[1] This example watershed was not used to derive figure 2.

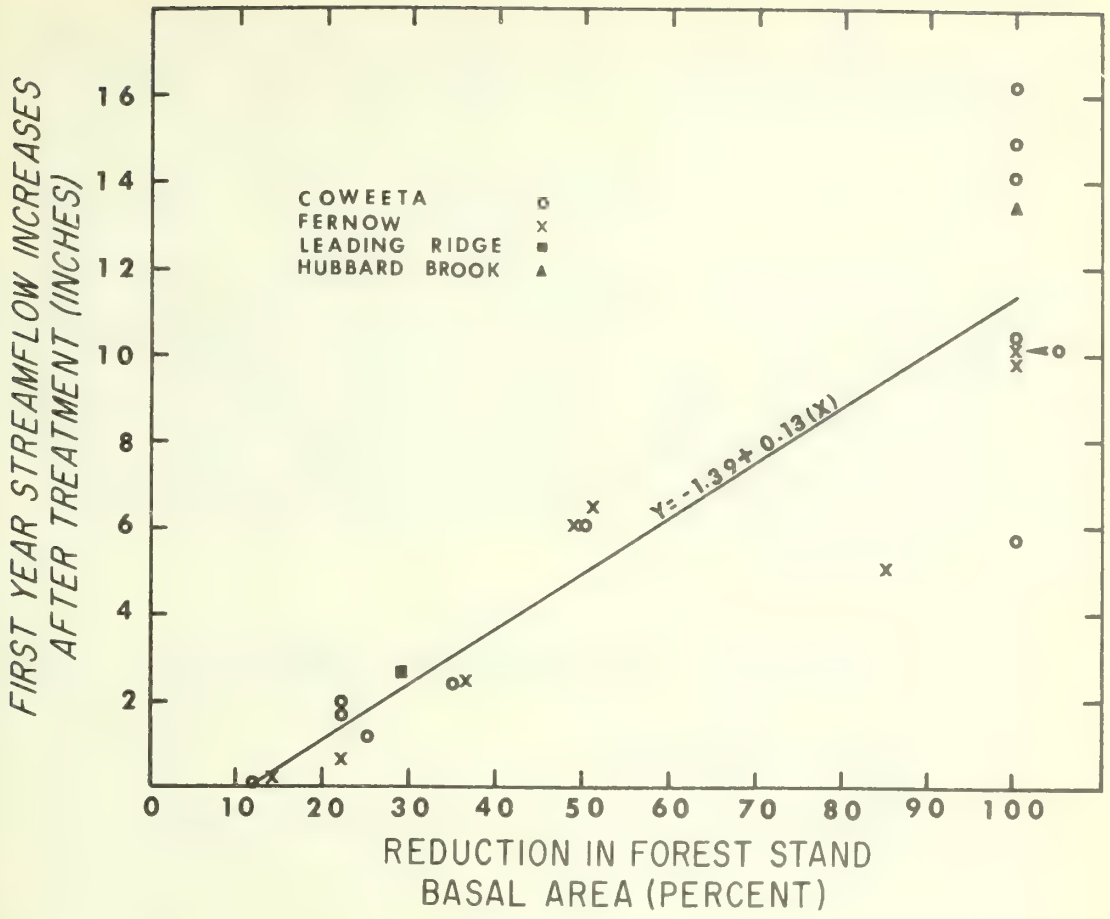

Figure 2.--Relationship between streamflow increase the first year after forest removal and the percentage reduction in forest stand.

capable of evaporating some of the extra water made available by the cutting, and the streamflow increase will be small. Even with the degree of accuracy afforded by the control watershed approach, a small increase in flow may not be detectable because of experimental error.

Catchment experiments have shown that treatment effects are largest the first year after treatment. In subsequent years, as the forest regrows, the evaporating surface area increases and streamflow increases diminish. In figure 3, the duration of streamflow increase has been related to the initial treatment response. The wide scatter of data is largely the result of differences in type of treatment and subsequent rates of regrowth; nevertheless, the depicted relationship indicates proportionality between variables.

If we can estimate the initial streamflow increase from figure 2 and the duration of the increase from figure 3, the total volume of water which

accrues from cutting can be approximated from the time trend of treatment effect. Kovner (11) and Hewlett and Hibbert (4) found that initial increase in streamflow declines with the logarithm of time. This trend is defined by the model:

$$Y_i = a + b \log T \quad (1)$$

where Y_i is the streamflow increase (inches) during the ith year after treatment, T is time (years) after treatment, and a and b are coefficients to be determined. This equation can be solved with figures 2 and 3: knowing the percentage of basal area cut, the initial streamflow increase, a, is defined. Having obtained a, figure 2 is used to estimate duration of the increase, T, at which time streamflow has returned to precutting levels (the yield increase equals zero). Thus figure 2, figure 3, and Equation 1 completely define the streamflow increase obtained by cutting Appalachian hardwood forests.

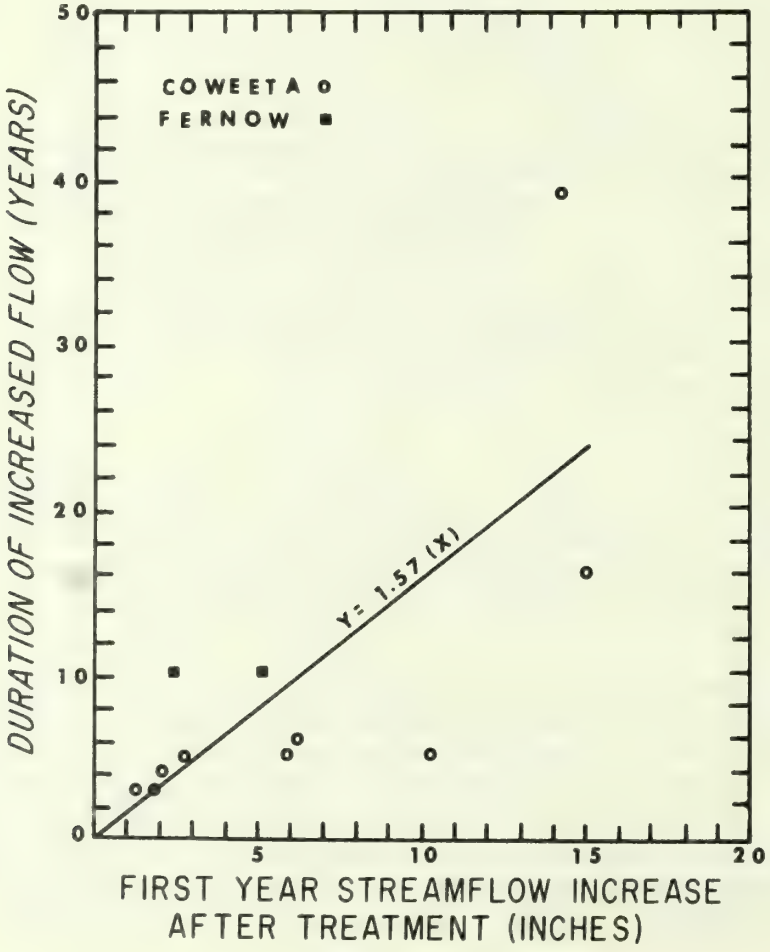

Figure 3.--Relationship between the duration of increase in streamflow and the first-year increase in flow after forest removal.

A PRACTICAL EXAMPLE

High-elevation, hardwood-covered Watershed 28 at Coweeta is 356 acres in size. This watershed was used to demonstrate intensive multiresource management of timber, water, and wildlife resources and recreational opportunity. Description of vegetation, soils, road system, and cutting prescriptions have been published (2). For this example, it is sufficient to state that 190 acres were clearcut and another 80 acres were given a combination thinning and understory cut. An overall 66-percent reduction in forest stand basal area was achieved over 20 months.

From figure 2, a 7.2-inch initial increase in streamflow is expected from the cutting, and from figure 3 the increases in flow are expected to persist until the 11th year. The prediction equation for the increase in annual streamflow for years Y_1, Y_2, Y_i is:

$$Y_i = 7.2 - 6.9 \log T \qquad (2)$$

The predicted and measured yield increases for each year since treatment are shown in table 2.

Table 2.--Comparison of predicted and measured streamflow increase for forest cutting on Watershed 28, Coweeta Hydrologic Laboratory, Franklin, N. C.

Year	Predicted increase	Measured increase	Difference in predicted-measured increase
		Inches	
1	7.2	6.5	-0.7
2	5.1	4.0	-1.1
3	3.9	3.1	-0.8
4	3.0	0.9	-2.1
5	2.4	1.1	-1.3
6	1.8	3.2	+1.4
7	1.4	4.1	+2.7
Total	24.8	22.9	-1.9

In this practical example, the predicted first-year streamflow increase was 0.7 inch more than the measured increase. The overestimate was expected because the first-year increase was calculated for the basal area removed over the 20-month period. During the first year of study, the actual basal area removed was somewhat less than this amount. The first-year yield increase determines, to a large extent, subsequent annual increases. As in this case, an overestimate of the

first-year increase will usually result in an overestimate of subsequent yearly increases and duration of the cutting effect (an underestimate of the first-year yield increase would have the opposite effect). Nevertheless, for the 7 years of record after cutting, the measured streamflow increase was only 1.9 inches less than was predicted (an underestimate of less than 10 percent). Considering the error in measured first-year increase and the scatter in figures 2 and 3, the agreement between predicted and measured streamflow increase in this example is sufficiently accurate for many purposes.

Reasonable agreement might be expected because Watershed 28 is located at Coweeta, one of the four sites of catchment studies; however, data from this watershed were not used to derive figures 2 and 3. To arrive at the final equations for predicting the first-year yield increase and the duration of the increase, we combined the data from Watershed 28 and the other 22 watersheds. The final equations are:

$$\text{First-Year Yield Increase} = -1.41 + .13\ (\text{Percentage Basal Area Reduction}) \quad (3)$$

$$\text{Duration of Yield Increase} = 1.55\ (\text{First-Year Yield Increase}) \quad (4)$$

YIELD DECREASES

If cutting a forest increases streamflow, then conversely the establishment and growth of a forest stand or reforestation can be expected to reduce streamflow. Fewer experimental data are available on the decrease in water yield associated with regrowth of a forest than are available on the increase in yield from forest cutting. But, Hibbert (6) indicates that streamflow declines by approximately .084 inch for every 1 percent of an area afforested or reforested, and this rate of reduction is smaller than the rate of increase in flow due to deforestation. Hibbert pointed out that this apparent lack of compatibility may not be real but simply may result from an insufficient range in experimental observations. When hardwoods are cut and the site is reforested with hardwoods, streamflow is expected to return to precutting levels when the forest matures. But, if agricultural cropland or grassland is afforested, the subsequent reduction in water yield will be proportional to the evapotranspiration difference between the original cover and that of the forest which replaces it.

Swank and Miner (18) showed conclusively that converting a mixed hardwood stand to eastern white pine substantially reduced streamflow of a southern Appalachian watershed because of interception and transpiration differences between the two forest types. Their information suggests that water supplies could be improved by favoring hardwoods over pine as a cover type for the catchment. In another experiment, Hibbert (7) found that after converting a hardwood-covered catchment to grass, Kentucky 31 Fescue, annual streamflow increased in proportion to the declining productivity of the grass. He found no difference in water yield from the two cover types when productivity of the grass was maintained

at a high level by fertilization, but streamflow increased by about 5 inches annually as the productivity of the grass declined over a period of 5 years. These studies illustrate the need for careful evaluation of vegetative alternatives in the management of water resources.

TIMING OF YIELDS

One objective of water resource development is to make water available when it is needed and in sufficient quantities so that withdrawals by man will not damage or destroy the aquatic environment. Augmentation of streamflow is often required during periods of low flow, and the engineer accomplishes this by controlled discharge of impounded water. Resource managers should also be aware of the opportunities for regulating the time distribution of flow afforded by vegetative manipulation.

The seasonal distribution of an increase (or decrease) in annual flow resulting from forest cutting varies somewhat throughout the Appalachian Highlands. At Coweeta, Watershed 17 was clearcut and maintained in a low coppice-herb condition by annual recutting for 7 years. Figure 4 shows the average monthly flow under a hardwood cover and the average monthly increase in flow during the recutting period. About 60 percent of the 8-inch increase in annual flow came in the period July through November, and the remainder came during the winter months. During the months of low flow (August, September, October), flow was increased by nearly 100 percent. Other experiments at Coweeta confirm this seasonal response to cutting.

In West Virginia where soils are shallower, almost all significant streamflow increases appeared from June through November (17). More important, deforestation of half a watershed in West Virginia changed the flow characteristic from intermittent to perennial (15). In Pennsylvania (13) and New Hampshire (9) significant increases in flow began in March because snow melted earlier than normal. Starting in June and lasting through October or November, large increases in streamflow resulting from decreased evapotranspiration were observed. Thus, experimental results consistently show that largest increases in flow obtained by cutting forests appear mostly in the growing and early dormant seasons when demand for water is greatest and flows are normally least.

The forest hydrologist is limited in exercising control over the flow regime--he cannot "turn on or turn off the tap" at will. Precipitation distribution and the melting of snow are important factors in determining when the extra water will be delivered. Hewlett (1) observed that monthly increases are strongly correlated with monthly rainfall at Coweeta where "it takes water to fetch water." When monthly rainfall is below some threshold amount, no increase in flow occurs, and base flow is derived mostly from water stored deep in the soil mantle. Rainfall above this threshold value will trigger the release of some of the accumulated evapotranspiration savings stored in the soil profile. Because of the large storage capacity of soils at Coweeta, some savings do not appear until January or February. At Fernow and Hubbard Brook, where soils are shallower, the accumulated reduction in evapotranspiration is recovered by December at the latest.

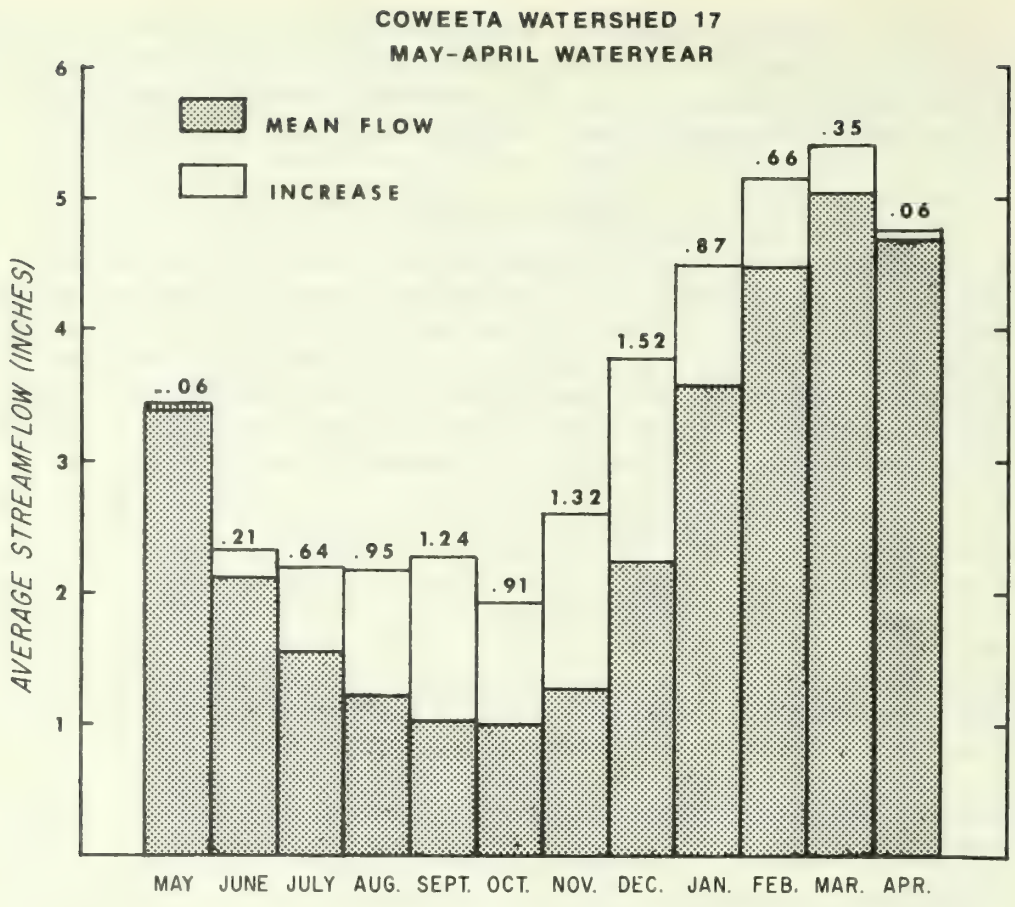

Figure 4.--Timing of mean flow before treatment and the average increase in flow produced by a Coweeta watershed which was clearcut and recut annually for 7 years.

STORMFLOW PEAKS AND VOLUMES

Experimental treatments which were specifically designed to document maximum sustained streamflow increases have shown that appreciable increases in peak discharge and stormflow volumes can occur. At Fernow, the lower half of one watershed and the upper half of a different watershed were deforested (15), and herbicides were used to control regrowth. Although no changes in dormant-season peak flows occurred on either treated catchment, peak discharge was significantly increased during the growing season on the watershed which had the lower half deforested. In an experiment at Hubbard Brook (9), all timber on a watershed was cut, no products were removed, and the watershed was maintained free from vegetation by herbicide treatment. The researchers found that growing season storm peaks larger than 20 cubic feet per second per square mile (c.s.m.) increased 22 to 246 percent and stormflow volumes increased 115 to 300 percent. However, the total stormflow volume in excess of 20 c.s.m., the primary contributor to downstream flooding, was less than 1 area-inch for the first 3 years after treatment.

An experiment at Coweeta indicates what may be a lower level of the stormflow response to clear-felling timber than that obtained farther north. In the experiment all vegetation was cut, but no forest products were removed and no roads were constructed on the watershed. Hewlett and Helvey (3) found that stormflow volume was increased by 11 percent overall (significant at .001 level) and peak discharge was increased by 7 percent (.05 level) but other hydrograph flow characteristics were not changed significantly. Individual stormflow increases attributed to deforestation ranged from 0 for small storms to 1.9 inches (a 22-percent increase) during a regional record storm lasting 7 days.

The response of peaks and stormflow volumes to commercial clear-felling may fall between these treatment extremes, and the response to partial cuts will be less than from clear-felling.

At Fernow, where a commercial clearcutting was done "loggers choice"--without stringent controls on road construction and logging methods--both peak discharge and stormflow volumes were increased somewhat (16). On the Leading Ridge catchment, where the lower 20 percent of a watershed was clearcut and logged, peak flows increased during the growing season when antecedent soil moisture content and rainfall intensity were high (13). No significant increase in peaks was observed for storms during the dormant season.

WATER QUALITY

Numerous measures of water quality are possible, depending upon the intended use of water resources. In forest watershed experiments, only temperature and turbidity have been measured with any consistency. Swift and Messer (19) measured effects of various types of vegetative management on weekly maximum stream temperatures at Coweeta. The greatest increase occurred when a hardwood forest was converted to a mountain farm--normal summer maximum temperatures of 67° F. were raised by 9 to 12 degrees. When hardwood trees in a cove site were deadened, summer maximum temperatures increased by 4 to 5 degrees, and winter maximums were only slightly affected. Subsequent clearcutting of the deadened timber raised summer maximums 5 to 6 degrees and winter maximums 4 degrees above the temperatures expected of streams flowing from undisturbed forests. An understory cut had little effect on summer or winter maximums, and after one clearcut watershed was revegetated by a dense coppice stand, summer maximum temperatures were slightly reduced. Studies have generally shown that forestry practices which open up the stream channel to direct insolation are the only practices which increase stream temperatures (13, 15).

Cutting trees, per se, does not influence stream siltation and turbidity, but improper road construction and removal of forest products have adverse effects. Hoover (8) reports turbidities of 7,000 p.p.m. during large storms at places logging methods and roads were not subject to controls, compared with 80 p.p.m. from an undisturbed watershed. Reinhart et al. (16) report storm period turbidities as high as

56,000 p.p.m. on a commercial clearcut where roads and logging methods were loggers choice, while maximum turbidity from a nearby undisturbed forested watershed was only 15 p.p.m. These high turbidities demonstrate the potential damage which can occur without controls to protect the water resource. On the other hand, when proper logging methods and road location and construction procedures are followed, only small and temporary increases in turbidity occur (1, 12, 13, 16). There is no longer any question that increases in both temperature and turbidity can be held within tolerable limits by exercising reasonable care in managing forested watersheds.

The impact of forest manipulations on water chemistry has seldom been documented. The most complete study in the East has been at Hubbard Brook where a catchment was clearcut, no products were removed, and herbicides prevented vegetative growth for three successive summers. Likens et al. (12) found in stream water large increases in concentrations of most ions studied and nitrate concentrations exceeded, almost continuously, the maximum levels for drinking water for the first 2 years after treatment. But this was an experimental cutting and not a recommended forest management practice because the watershed was intentionally maintained free from vegetation. Contrary to findings at Hubbard Brook, the results of experimental treatments at Coweeta have not shown an accelerated loss of ions to the streams.[2] Further study is needed to provide adequate information on the interrelationships between common management practices and water chemistry.

DISCUSSION AND CONCLUSIONS

In the past, forest hydrologists have been reluctant to extend results from experimental watersheds to other forested areas. The reluctance is understandable for two reasons. First, results derived in one region have sometimes been indiscriminately applied in another geographic area where similar responses could not be expected. In this report, the area for which the relationships were developed is delineated in figure 1. The reader should be aware, however, that in limestone formations the increase may not appear in the basin in which the cutting is made. Part of the increase may leave through underground channels to reappear at some point farther downstream. Also, the yield increase obtained from cutting pine will be greater than from cutting hardwoods (17, 18); therefore, Equation 3 is valid only for forests comprised primarily of mature hardwoods and will underestimate streamflow increases from coniferous forests.

A second reason for reluctance to extend catchment results is the large difference in streamflow increase which is sometimes observed after two watersheds are treated in a similar manner. This is apparent

[2] Swank, W. T., and Elwood, J. W. The seasonal and annual flux of cations for forested ecosystems in the Appalachian Highlands. (Paper presented at Second Natl. Biol. Congr., Miami Beach, Fla., Oct. 23-26, 1971.)

from data for the 100-percent cuts (fig. 2). We know that much of the observed scatter of data occurs because the watersheds differed in slope, aspect, vegetative density, rainfall, and perhaps other factors; thus, the scatter was to be expected. We concede that a high degree of accuracy may not be obtained for an individual watershed which varies appreciably from the "average" watershed represented by Equations 3 and 4. To dwell on this point, however, is to miss the significance of the information presented: The ability to predict changes in water yield makes it possible, for the first time, to consider vegetative management in protecting and developing water resources for large areas. Because a large watershed contains a variety of slopes, aspects, soils, and vegetative conditions, Equations 3 and 4 should provide a reasonably good estimate of the average streamflow response to forest cuttings.

We can conclude from the experimental watershed evidence in the Appalachian Highlands that cutting forest vegetation has a favorable impact on the water resource by supplementing man's supply of fresh water when consumptive demands are most critical. And, the amount of extra water produced can be predicted with a degree of accuracy which is sufficient for many purposes. Although heavy forest cuttings will usually increase some stormflow characteristics on that portion of the watershed cut over, regulated cutting on upstream forest land will not produce serious flood problems downstream. Studies have also demonstrated the adequate methods that will hold water temperature and turbidity increases within tolerable limits--usually it is a question of applying existing knowledge in the management of the watershed. Much less is known about the influence of forest cutting on the chemical composition of water.

As studies of cause and effect relationships between vegetation, soils, climate, and streamflow produce new information, improved models will be developed for predicting the effects of various forest management practices on the quality, quantity, and timing of streamflow. Meanwhile, the summary data from these 23 watershed experiments provide the best information available on how cutting hardwood forests in eastern United States modifies streamflow.

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Douglass, James E., and Swank, Wayne T.
1972. Streamflow modification through management of eastern forests. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-94, 15 pp.

Equations for predicting the first-year yield increase, duration of the increase, and the total volume of water which occurs from cutting forests are presented. The equations are based on a summary of 22 experimental cuttings of hardwood forests in the Appalachian Highlands. Predicted yields are compared with actual yields obtained from a logged watershed. The paper also discusses the effects of forest cutting on the seasonal distribution of increased annual flow, stormflow peaks and volumes, and water quality characteristics.

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The Bayesian Controversy

by

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The Bayesian Controversy

by

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§ 1 INTRODUCTION

There has been a recent revival of interest in Bayesian statistical methods, partly due to the appearance of a theory of games (von Neumann and Morgenstern 1944) and the publication of Abraham Wald's book (Wald 1950) on decision theory. The Wald book and the von Neumann book were not Bayesian but they did encourage the view that statistical inference is an activity where costs (perhaps monetary, perhaps not) accrue to every decision of the statistician. Leonard J. Savage and a few others have subsequently argued with some success that only Bayesian methods satisfactorily concern themselves with these costs (cf. Savage 1962, especially the section on Simple Dichotomy).

On the other hand, R. A. Fisher explicitly rejected Bayesian methods as a tool for experimental science (cf. Fisher 1925, chapter 1, and Fisher 1935, chapter 1) and built instead on the pioneering work of W. S. Gossett ("Student" 1908). And Jerzy Neyman has been an articulate spokesman of the non-Bayesian schools of statistics ever since he published a theory of confidence interval estimation (Neyman 1934).

So statistical inference in general and Bayesian inferences in particular continue to be controversial. M. G. Kendall (1968) put it well when he said to the Royal Statistical Society in London,

> Twenty five years ago I presented a paper to this society ... it correctly predicted most of what was to happen in the statistical world, except I got my time scale wrong -- what I thought would take twenty years only took ten; and it was spectacularly in error on one point, for I thought that different schools of statistical inference would have argued themselves to a standstill ..., whereas in actuality they are still hammering away at one another with undiminished zeal.

I am going to try to describe for amateur statisticians something of what this conflict is about. I will take confidence interval estimation as advocated by Neyman as representative of familiar non-Bayesian methods. I will review what a confidence interval is (§ 2), and then emphasize (as critics do) one or two things that it is not (§ 3). Next, I will illustrate a Bayesian inference (§ 4) and repeat (§ 5) what appears to me to be an astute summary of what is wrong with the Bayesian methods. Finally, I will try to indicate the implications for experimental scientists (§ 6).

Incidentally, I will use some rather small samples when the principle to be illustrated does not depend on sample size.

§ 2 CONFIDENCE INTERVAL ESTIMATION

Suppose you would like to know the average height of the trees in a large plantation on a uniform site. Assume the heights are normally distributed. Suppose you are willing to measure the heights of the trees in a random sample of size n where n is not too big.

Neyman's great contribution was the observation that with no other assumptions you can convert the observed heights into an informative statement about the average height of the plantation based on the following argument.

Your sample, denoted here by $X_1, X_2, \ldots, X_n$, is to consist of n independent observations from a normal distribution. Let the mean of that distribution be denoted by μ and the variance by σ^2. Then μ is the average height which you want to know. Both μ and σ^2 are taken to be unknown constants. Further, let $\bar{X}$ be the sample mean and $S_{\bar{X}}$ be the estimated standard error of the mean, i.e., let

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad \text{and} \quad S_{\bar{X}} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n(n-1)}} \,. \tag{1}$$

Then the following a priori probability statement can be deduced, viz.,

$$\Pr\left(\bar{X} - t_\alpha S_{\bar{X}} \le \mu \le \bar{X} + t_\alpha S_{\bar{X}}\right) = 1 - \alpha \tag{2}$$

where α is an arbitrarily chosen real number between zero and one, and t_α is the $(1 - \alpha/2)^{\text{th}}$ quantile of "Student's" distribution with n - 1 degrees of freedom. The family of intervals

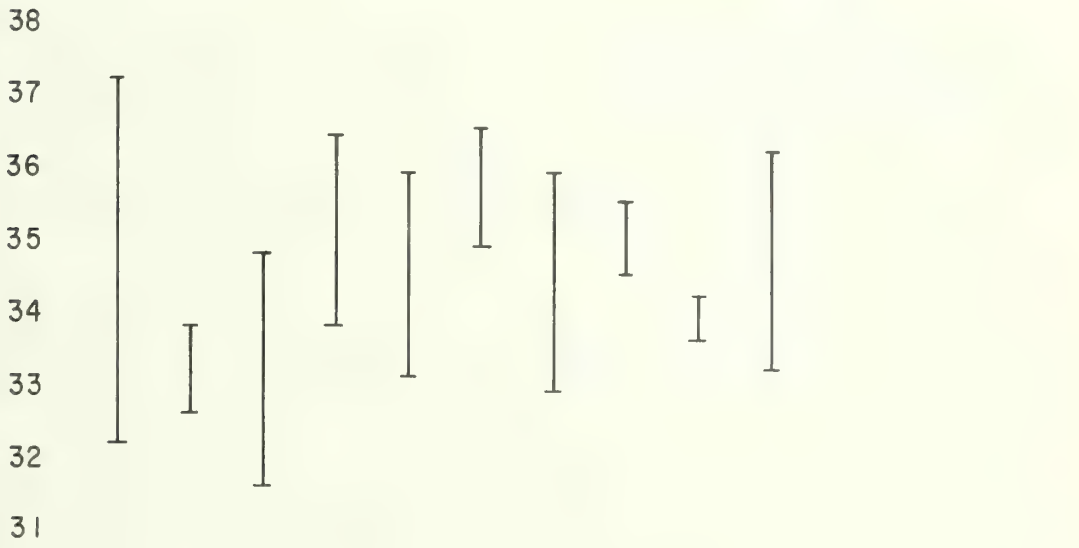
$$\left[\, \bar{X} - t_\alpha S_{\bar{X}} \,,\quad \bar{X} + t_\alpha S_{\bar{X}} \,\right]$$

is called $(1 - \alpha)$% confidence intervals for μ. The number $1 - \alpha$ is called the confidence coefficient.

To be specific, let α be, say, .25. Then equation (2) says that prior to sampling there is a probability of .75 that the 75 percent confidence intervals

$$[\bar{X} - t_{.25} S_{\bar{X}}, \quad \bar{X} + t_{.25} S_{\bar{X}}] \tag{3}$$

will contain the parameter, μ. An operating interpretation of this statement is required for clarity. If you were to repeatedly take random samples of size n from your plantation and compute each time an interval according to the formula (3), the observations would vary from one sample to the next. So would the sample mean ($\bar{X}$) and standard error ($S_{\bar{X}}$). Thus, the location and the widths of the intervals would vary in repeated sampling (cf. fig. 1). Even so, the family of intervals produced in this way would contain μ about 75 percent of the time. That is what (2) implies.



1	2	3	4	5	6	7	8	9	10	SAMPLE NUMBER
37.2	33.8	34.8	36.4	35.9	36.5	35.9	35.5	34.2	36.2	CONFIDENCE INTERVAL
32.2	32.6	31.6	33.8	33.1	34.9	32.9	34.5	33.6	33.2	

Figure 1.--Seventy-five percent confidence interval for μ for 10 samples, each of size 4.

In a similar way, 99 percent confidence intervals contain the parameter about 99 percent of the time. And so on for other confidence coefficients.

Considering this operating characteristic, the single numeric interval based on a single sample is apparently an imperfect indicator of μ. But, for confidence coefficients close to 1 you may reasonably be willing, according to Neyman, to claim that the average height is in the computed interval, or to act as if you knew it was. Because if you do

this habitually when you are confronted with diverse problems that require estimates of unknown parameters (always choosing confidence coefficients close to 1), then your assertions will be correct and your actions appropriate most of the time. Thus, good results are guaranteed in the long run.

§3 CRITICISM OF CONFIDENCE INTERVAL ESTIMATES

What are the criticisms of Neyman's procedures? One Bayesian (Pratt 1961) says of the Neyman-Pearson formulation in general, "it is so ingenious and so successful that it is liable to be credited with properties which it does not have and which its originators and developers have never claimed for it." Experimentalists should be aware of the fact that no particular numeric confidence interval is a probability statement. I will emphasize this point since it is apparently not widely appreciated.

I have drawn 10 samples, each of size 4, from a population of normally distributed tree heights. For each sample, I have computed a 75 percent confidence interval for the mean height, μ. These intervals are recorded and plotted in figure 1.

The first confidence interval is [32.2, 37.2]. Suppose someone, contrary to Neyman's instructions, insists this means

$$\Pr(32.2 \leq \mu \leq 37.2) = .75. \tag{4}$$

It is easy to show that the interpretation (4) leads to an absurdity, for surely if the interpretation (4) applies to the first interval, it applies equally to each of the others. Therefore, from the eighth interval

$$\Pr(34.5 \leq \mu \leq 35.5) = .75, \tag{5}$$

from the ninth

$$\Pr(33.6 \leq \mu \leq 34.2) = .75, \tag{6}$$

and from the tenth

$$\Pr(33.2 \leq \mu \leq 36.2) = .75.$$

But recalculate this last probability as follows. The probability that μ is between 33.2 and 36.2 inclusive must be at least as big as the sum of the probabilities computed in (5) and (6) (cf. fig. 1). Thus,

$$\Pr(33.2 \leq \mu \leq 36.2) \geq .75 + .75 = 1.5.$$

The interpretation (4) leads not only to contradictory probabilities but to the conclusion that some probabilities are bigger than one. The statement (4) is invalid. A numeric confidence interval is not a probability statement.

A further indication that the probabilities that are defined in the theory of confidence interval estimation apply before and not after the experimental results are in hand has been given by Buehler (1959). To see the essence of his argument, consider whether you would be willing to play the following game for money against me.

Figure 1 shows ten 75 percent confidence intervals for the unknown mean of a particular normal distribution. Suppose we have an automatic and infallible computer that will continue to draw random samples of size 4 from that distribution, and compute from the results of each sample a 75 percent confidence interval for the mean according to equation (3). After a large number of intervals have been computed, the machine will (somehow) determine the actual value of the mean and print it out for us. The question is, would you be willing to make some wagers on whether individual intervals contain the mean? You see, we could keep records of each interval and how we bet. In the end, when we find out the actual value of the mean, we could determine the net payment to be made to the overall winner. In particular, would you be indifferent about giving odds of 3 to 1 that a 75 percent confidence interval contains the parameter and giving odds of 1 to 3 that it does not? Would you be willing for me to decide for each sample which wager you make? Buehler argues that your answer should depend on whether in each case the wagers are to be placed before the sample is drawn or after the interval has been computed.

Take the case where the wagers are to be placed in each case prior to sampling. I think your intuition will tell you that you may as well let me decide which wager you make. Even if you do, the game is, in fact, a fair one. We each still have an equal chance of being the ultimate winner.

On the other hand, if the wagers are to be placed after the sample is in and the interval computed, then you should not be willing for me to decide which bet you make, for I could adopt the following strategy. Notice that the average length of the ten intervals already computed is about 2.5. For convenience, let us define an interval to be long if it is longer than 2.5; call it short otherwise. On every trial that produces a long interval, I will require you to bet that the interval does not contain the mean; on the trials that produce short intervals, I will require you to bet that the interval does contain the mean. Look again at figure 1. Would you be willing to continue the sampling process, betting 3 to 1 that the short intervals contain the mean and 1 to 3 that the long ones do not? It would not be a fair game, and you should expect to lose.

So, the confidence coefficient determines fair betting odds if the bets are to be placed prior to sampling. But we have just seen that it may not if the bets are to be placed after the interval is computed.

The confidence coefficient thus does not give the probability that a particular numeric interval contains the parameter. Such probabilities are not defined. For the mathematically inclined the source of the difficulty is clear. The nonexistence of probabilities associated with a

particular confidence interval is a consequence of the assumption that the parameter to be estimated is a constant (cf. paragraph containing equation (1)). This puts three relevant constants in hand when a numeric confidence interval has been computed, viz., the unknown parameter and the two numeric end points of the computed interval. And, no real number is contained between two others with a probability strictly between 0 and 1.

§ 4 BAYESIAN ESTIMATION

Bayesians prefer to try to make probability statements that are contingent on the observed sample results. It appears that, at least occasionally, such statements can be made.

For example, suppose a manufacturer requires mostly dense wood for one of his products, and a single producer has contracted to supply dense wood for a premium. Let individual bolts of wood be called defective if their specific gravity is less than some specified number. Suppose the contract requires that the proportion, p, of defective bolts in each car be .30 or less. Imagine that it is your job to determine whether individual carloads of wood meet the specifications of the contract, and to divert to some other operation those cars that fail. Your objective for each carload of wood is

accept the car if $p \leq .30$;

divert the car if $p > .30$.

Now, suppose that your records show that the distribution of the proportion of defectives in carloads of wood received so far follows a beta distribution with parameters 2 and 10 (fig. 2). You may be willing to assume that the proportion of defectives in a load awaiting your decision is a random observation from this distribution. Then the distribution in figure 2 is called the prior distribution for the proportion of defectives in the car.

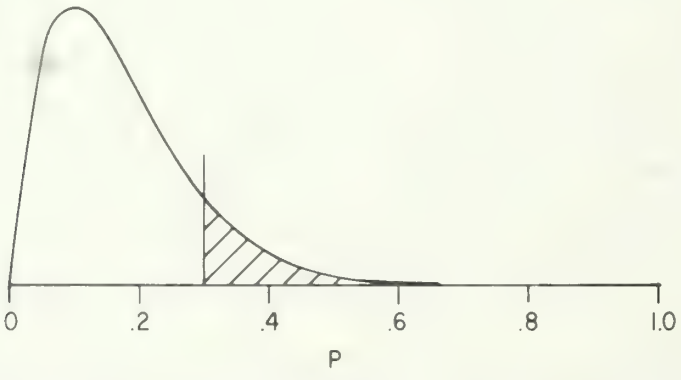


Figure 2.--Prior distribution of p, the proportion of bolts defective in carloads of wood.

Given these assumptions, you can make probability statements about carloads of wood. For example, based on the historical records alone, the probability that the current load of wood will meet the specifications is .89 (the tail area, shaded in figure 2, of the prior distribution is .11 (cf. Pearson 1968)).

Finally, suppose that you have just enough time and resources to measure the specific gravity of 4 randomly selected bolts from each incoming car before you make a decision on the car. Then, what you would like as a basis for your decision about each car is the probability that the load will meet specifications when the number of defective bolts in the sample is found to be x = 0, 1, 2, 3, or 4. Bayes' theorem implies that you get that by multiplying the prior distribution by the likelihood function of the sample. The product is called the posterior distribution of the parameter. In symbols,

$$P(p|x) \propto P(p)\ P(x|p)$$

i.e., the probability of the parameter, p, given the sample, x, is proportional to the product of the prior probability of the parameter and the probability of the sample given the parameter.

Bayes' theorem itself is noncontroversial, so the arithmetic details of its application can be omitted here. In this example, the posterior distribution of p, when x defectives in a sample of 4 are observed, is a beta distribution with parameters 2 + x and 10 + (4-x). If the sample results in either 0, 1, 2, 3, or 4 bolts defective, then the posterior distribution of the proportion of defectives in the car is given in figure 3.

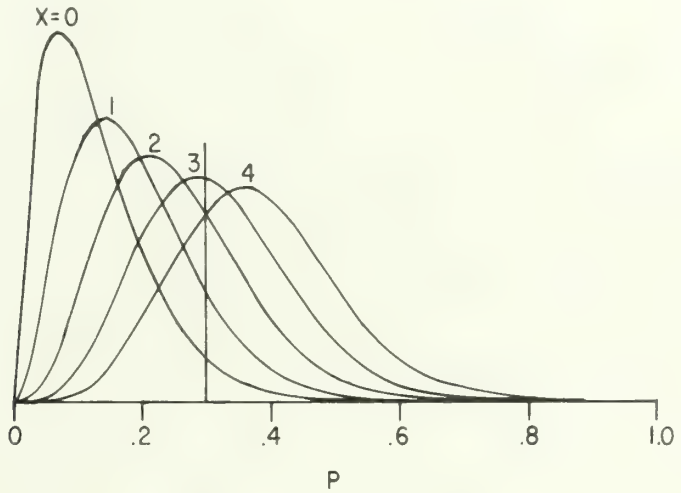


Figure 3.--Posterior distributions of p when x bolts in a sample of 4 are defective.

These posterior distributions provide a mechanism for making probability statements that take into account the historical record and the sample results. For example, if there are no defectives in a sample of 4 bolts from a particular car, then the probability that that carload

will meet specifications is .96. That is the area under the posterior distribution up to p = .30. The operational interpretation is that if only those cars that produce a sample with no defectives are considered, the distribution of p is given by the posterior distribution corresponding to x = 0, and 96 percent of those cars meet the specifications.

More completely,

$$\begin{array}{lll} \text{when } x = 0, & \Pr(p \le .30) = .96 & \\ \quad 1 & .87 & \\ \quad 2 & .70 & (7) \\ \quad 3 & .48 & \\ \quad 4 & .29 & \end{array}$$

On the basis of these probabilities you might decide, for example, to

$$\begin{array}{l} \text{accept the car if } x = 0 \text{ or } 1; \\ \text{divert the car if } x = 2, 3, \text{ or } 4. \end{array} \qquad (8)$$

Some arithmetic shows that if this decision rule is adopted, about 7 percent of those cars accepted will fail to meet specifications (compared to about 11 percent of all the shipments of the producer). The improved quality of the accepted lots is achieved by diverting about 15 percent of the incoming cars.

Whether rule (8) or some other is the optimum rule in this example depends partly on economic considerations; in particular, the cost of accepting a car that does not meet the specifications and the cost of diverting one that does. And, of course, better screening could be achieved with a larger sample from each car. The more important thing to note here is the type of information that derives from the Bayesian procedures as indicated by the probabilities in (7).

It is often admitted that, in many examples like the one here, the idea of taking a prior distribution for a parameter and modifying it in the light of sample evidence is an intuitively satisfying one. And the dynamics of the Bayesian solution are frequently quite appealing. Notice from figure 3 how the prior distribution is modified when a sample with no defectives is observed. The modification is supposed to be a precise quantitative measurement of the natural increase in your confidence that the load will meet the specifications. Alternatively, the posterior distribution corresponding to 3 or 4 defectives in a sample is supposed to reflect the increased suspicion of a load that produces so many defective sample bolts.

Finally, Bayes' theorem naturally suggests certain principles of estimation, especially the likelihood principle, and has considerable appeal to some non-Bayesians. Savage (1962) and Birnbaum (1962) give an intuitive and a technical discussion, respectively, and references.

§5 CRITICISM OF BAYESIAN TECHNIQUES

Why then are Bayesian methods so little known in practical disciplines, and why did Fisher and so many others reject them? Well, difficulties with these methods often surface immediately when one tries actually to apply them. Reconsider our first problem of estimating the average height of a large plantation and the difficulty of estimating the prior distribution of that parameter. And in the last example, what should be done if there are only very limited or imprecise records on the past performance of the producer, or no records at all? In such cases, some Bayesians say that you may have to subjectively specify the prior distribution, i.e., just say what you think it is. A fundamental and vigorously contested question then arises: What then is the utility of the result?

To get some insight, consider again figure 3. The mechanism that generated these nice results depends on the specification of the prior distribution in figure 2. If that prior distribution was improperly specified, then the posterior distributions must be, to some extent, inappropriate. The possibility that posterior distributions may be grossly inappropriate, and hence misleading because of improper specifications of the prior distribution, is one of the concerns that has prompted followers of Fisher, Neyman, and others to reject the Bayesian methods.

Note that the argument as presented so far is a philosophical one. The Neyman and, except in those cases where the parameter is a random variable whose prior distribution can be described with considerable confidence, the Bayesian arguments are each distinctly vulnerable to criticism, as we have seen. When a confidence interval has been computed, confidence that it contains the parameter may be augmented or diminished in an unaccountable way. The Bayesian interval truly reflects the experimenter's assessment of the situation, but the results may be misleading if his assessment of the situation underlying the experiment is in error. Apparently, there will always be two opinions, each widely held, about which of these deficiencies is more serious.

At least in the general area of scientific research (as opposed to, say, industrial quality control), Irwin D. J. Bross (1969) has described an alternative view which he claims is subject to empirical verification. He focuses on the communication network that connects the scientists in a particular discipline with the practitioners in the discipline. Correct impressions, interpretations, and assertions that flow through the network are signals. False or misleading ones are noise. Bross claims that in many scientific disciplines, e.g. pharmacology, a generation ago subjective analyses often influenced individual transmissions. He claims that as a result the noise levels in these networks were high and the disciplines ill-received. He further claims that it is a matter of

historical record that modern non-Bayesian statistical methods have subsequently been successful in drastically reducing the noise level in these networks. He says of confidence intervals,

> ... Suppose that all of the doctors testing a given class of new drugs carry out well-designed placebo-controlled clinical trials and that they report their results as confidence intervals .... Assuming that the studies are well done and that appropriate ... 95% ... confidence intervals are always reported, ... the noise level will be about 5%. ... This is why the language of modern statistics has become one of the most widely-used languages in scientific communication.

Bross goes on to say that, contrary to this record of admirable performance "in thousands of actual scientific applications," subjective methods "have not been successful in any." Thus, Bross contends that the choice is between Neyman (and other nonsubjective) methods that have actually worked in practice and Bayesian methods based on subjective prior distributions which have no records of success in realistic and concrete applications.

§6 CONCLUDING REMARKS

If a parameter is to be estimated from sample evidence, and if it varies according to a prior distribution which can be correctly specified, then generally the most informative statement possible is a description of the posterior distribution of the parameter computed according to Bayes' theorem. These cases may be relatively rare in experimental science.

In the other cases, it appears to me that Bross and Buehler have challenged researchers and consulting statisticians in a way that cannot be ignored. Bross has challenged those who use subjective prior distributions to demonstrate that they can control the noise level in their communications. I believe that a majority of statisticians are apprehensive of subjective methods in the absence of such a demonstration (e.g., one might prove that the conclusions reached are insensitive to the specification of the prior distribution).

Buehler has implicitly challenged those who choose Neyman's methods to use them just for the very remarkable properties which they actually have. In spite of the fact that posterior probabilities are not defined, they guarantee good results in the long run.

APPENDIX

Ten random samples are described in §3. These samples are composed of the first four observations in the ten columns on page 1 of the Table of Gaussian Deviates published by the Rand Corporation (1955). Due to a linear transformation of the tabulated quantities, the samples are actually from a normal distribution with mean 35 and variance 4. Because researchers never know the values of the parameters they are trying to estimate, this information was withheld in the text for added realism.

Perhaps it should be noted that, in spite of the fact that many pairs of the 75 percent confidence intervals depicted in figure 1 are disjoint, seven of them contain the true mean. And, of course, this is as close to a 75 percent success ratio as can be obtained in ten trys.

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WARPING IN SOUTHERN PINE STUDS

by

L. I. Gaby

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U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
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WARPING IN SOUTHERN PINE STUDS

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INTRODUCTION

Southern pine has been a favorite building material in America for centuries because the old-growth forests produced high-strength, straight-grained, and durable building products. After World War II, demands for building material were so strong that southern pine dimension lumber from second-growth forests was shipped green to the market. As houses were constructed with still-green studs, joists, and other structural members, certain problems began to occur. Subsequent in-place shrinkage caused warping that distorted walls, created cracks in plaster and wallpaper, distorted openings for doors and windows, and in general created a bad image for wood construction. The finger was pointed at southern pine, but second-growth material from other softwood species caused similar problems when used in the green or semidry condition.

It should be emphasized that the industry has recognized the problem and has worked diligently to promote practices that would minimize warping during and after construction. Improved lumber standards and grading rules at the national level now require lower moisture content and restrict visible compression wood, two important factors related to shrinkage. Additional self-analysis by the industry is needed to further improve the quality and use of wood in construction in order to meet the ever-increasing pressure from competitive materials.

At the present time, the grading rules commonly used for southern pine 2 by 4 dimension, as well as those for the more recent stud grade, contain several provisions which are related to the problems of dryness and warping. The provisions concern the presence of compression wood, which is prohibited if in readily identifiable and damaging form; pith, which is not limited; and moisture content, which cannot exceed 19 percent.

Compression wood is an abnormal type of wood which usually develops on the underside of leaning stems or limbs of softwood trees.[1] Such wood ranges in form from mild to severe, depending upon the severity of lean. Extreme lean produces severe compression wood, which is easily distinguished in the log or board. Logs containing compression wood usually exhibit an

[1]Pillow, M. Y., and Luxford, R. F. Structure, occurrence, and properties of compression wood. U. S. Dep. Agric. Tech. Bull. 546, 32 pp. 1937.

out-of-round cross section, with the compression wood along the longest radius from the pith (fig. 1). Annual rings are usually wide along this radius, and the wood is darker in color than normal wood, with no distinct change between earlywood and latewood. Compression wood is usually most evident in butt logs. Although it may be found in any position of the tree, in most cases it occurs near the pith, indicating that trees often lean during the juvenile stage. The most damaging characteristic of compression wood is that it shrinks along the grain to a much greater degree than does normal wood. When normal wood is combined in the same piece, such longitudinal shrinkage in the compression wood will be inhibited by shrinkage of the adjacent normal wood, but the shrinkage will nevertheless be great enough to cause the piece to warp.

Figure 1.—Cross section of log containing severe compression wood.

The pith, a part of the growing point of the main stem, is located at the very center of the cross section in a typical tree. The first-formed material surrounding the pith for several years is typically fast growing, relatively light, and is called juvenile wood. Like compression wood, its longitudinal shrinkage in southern pine is excessive and is responsible for much warping.

The relationship between moisture content, shrinkage, and warping is an established one: Without a decrease in moisture content, shrinkage cannot occur; and without a change in moisture content, warping cannot occur. The most serious amount of warping results from shrinkage during the drying process.

Recently, several studies conducted throughout the Southeast have contained recommendations that moisture contents for wood used in houses be lower than 19 percent. In 1960, Hopkins[2] recommended that structural lumber be installed at 10 to 11 percent moisture content. In 1967, Taras[3] reported that the maximum level of wood moisture content is reduced from about 15 percent to about 8 percent when air conditioning is used, a practice which is becoming more common in new homes built in the warmer Southeastern States.

Many studies have documented the problem of warping in wood structural members. The present study attempts to show the basic problem in southern pine studs at different levels of moisture content with studs from second-growth pine of various growth characteristics.

MATERIALS AND METHODS

One hundred and twenty 2 by 4 studs 8 feet long were carefully resawn from green shortleaf and loblolly pine cants and green rough dimension lumber so that the effect of pith location and ring orientation on the various types of warping could be firmly established. Sixty of these were matched studs: those cut from the same cant resulted in pairs of face-matched studs; those cut from the same wide piece of dimension resulted in pairs of edge-matched studs. Twenty-six studs were face-matched, and 34 were edge-matched. Most studs were sawn so that the pith was contained within the stud completely and also located adjacent to one edge if possible, but, because of the prevailing tendency of the pith to deviate in its growth pattern, not all studs conformed with this configuration (fig. 2). Some studs were completely free of pith. Ten of these were flat-sawn (annual rings tangent to the wide face) and 10 were quarter-sawn (annual rings

[2]Hopkins, W. C. Moisture content of building structura members. Forest Prod. J. 10(10): 506-508. 1960

[3]Taras, M. A. Moisture content variation of finishe and partially finished wood in homes in the Southeast. Fores Prod. J. 17(8): 60-63. 1967.

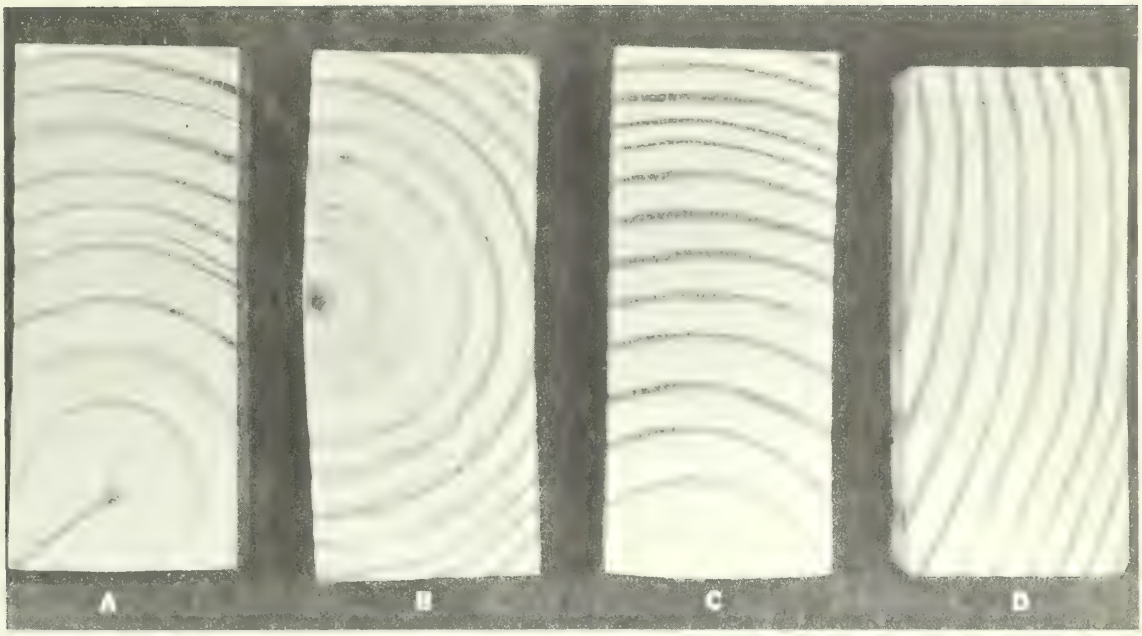

Figure 2.—Mid-length cross sections of typical test studs. Note location of pith and ring orientations: (A) pith at edge; (B) pith at face; (C) no pith, quarter-sawn; and (D) no pith, flat-sawn.

tangent to the stud edge); both of these types are produced commercially either in the initial log breakdown or in resawing. No studs with visible compression wood were included.

Although conventional industry practice is to surface after drying, the studs were surfaced on four sides while in the green condition so that small changes in shrinkage and warp could be measured accurately to the limit of available instruments. During testing, half of the 120 studs were partially restrained in rigid frames constructed of clear, straight-grained, kiln-dried material. The restraint was applied, as in typical construction, by toenailing at each end only, or by using a dovetailed joint between studs and plates, the latter being a joint used in factory-built wall frames. The other 60 studs were hung from hooks during testing, allowing complete freedom of movement.

Warp of the restrained studs was measured with the studs in place within a reference frame independent of, and surrounding, the studs. The free-hanging studs were periodically taken down and measured for warp on a specially constructed table. In both types of test, displacements (warp) of the stud faces were measured to the nearest 0.01 inch. Shrinkage was measured to the nearest 0.001 inch at the same time. These measurements were made daily for the initial 10 days and at longer intervals thereafter until the study was terminated. Measurements of warp included bow, crook, and twist for all studs. By definition in the current National Grading Rule,[4] bow is a deviation of the wide face from a straight line in a plane from end to end, crook is a similar deviation of the narrow face or edge, and twist is a spiraling of the ends so that neither the face or edge will be completely in contact with a flat surface when at rest (fig. 3).

Temperature ranged between 72° and 80°F., with air circulating at velocities of 100 to 200 feet per minute. No special attempt was made to control the equilibrium moisture content. It averaged 6 to 9 percent during most test periods, and final wood moisture contents averaged about 10 percent.

The moisture content of the studs at the beginning of testing ranged from 50 to 140 percent. Changes in moisture content were determined by weighing supplementary full-length studs at the same time warp was measured. Additional measurements were made with a resistance-type moisture meter after the studs reached 30 percent moisture content. Testing was terminated when moisture contents of the studs reached a plateau

[4]U. S. Department of Commerce. National grading rule for dimension lumber. Off. Eng. Stand. Serv. Current as of Aug. 1, 1971.

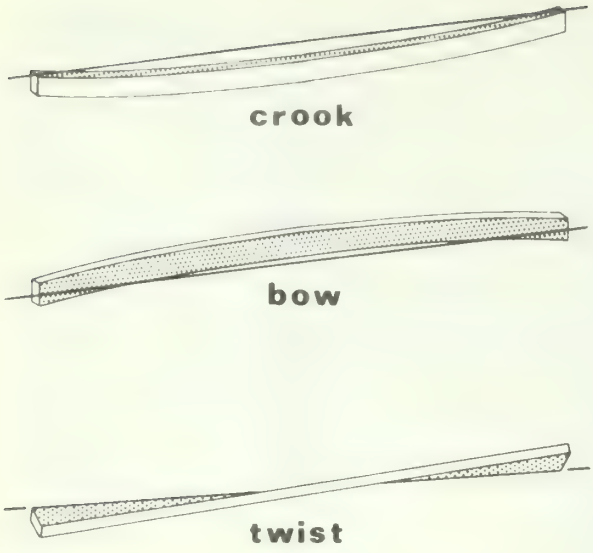

Figure 3.—Simple forms of warp in studs.

of about 10 percent and remained there for 5 to 10 days, resulting in a total test period of 32 to 35 days.

After testing was completed, moisture contents were confirmed by cutting representative blocks from the studs at 1-foot intervals and subjecting them to standard ovendrying. At the same time, the possible presence of compression wood not apparent on the exposed surfaces during initial selection of the studs was determined by cutting thin (1/32-inch) sections at the 1-foot intervals and examining them on a lamp table.[5]

RESULTS AND DISCUSSION

For analysis, the studs were grouped primarily according to absence or presence of the pith and presence of compression wood in the pith area. Other groupings were also made according to orientation of the growth rings to stud faces, position of studs sawn from the same cant or piece of rough dimension, and type of restraint. A summary of means for the various stud groupings is shown in table 1. These means may be compared with the maximum allowances for warp in 2 by 4's 8 feet long as set by the National

[5]Pillow, M. Y. A new method for detecting compression wood. J. For. 39: 386-387. 1941.

Table 1. — Warp values for various stud types and treatments

Analysis group number	Stud type or treatment	Total studs	Mean values for warp			Studs exceeding National Grading Rule limits		
			Crook	Bow	Twist	Crook	Bow	Twist
		No.	*- - Inches - -*			*- - - Percent - - -*		
1	No pith nor significant compression wood[1]	38	0.17	0.26	0.18	21	3	18
2	Containing pith— no significant compression wood[1]	58	.36	.34	.23	53	12	21
3	Containing pith and significant compression wood[1]	24	.72	.60	.20	79	25	21
4	Flat-sawn—no pith	10	.11	.23	.10	10	0	0
5	Quarter-sawn—no pith	10	.06	.06	.03	0	0	0
6	Face-matched—all types	26	.47	.45	.18	58	15	12
7	Edge-matched—all types	34	.39	.41	.43	59	15	56
8	Restrained	60	.32	.30	10	38	8	2
9	Free-hanging	60	.42	.55	.43	58	15	37

[1]Significant mild compression wood: that amount contained in the first three annual rings in streaks at least 4 feet long.

Grading Rule (table 2). Discussion of the results is concerned primarily with crook because it is the most difficult type of warp to remedy in construction.

Table 2.—Maximum warp allowed by the current National Grading Rule in 2 by 4's 8 feet long

Dimension lumber class	Crook	Bow	Twist
	Inches		
Stud	0.25	0.75	0.38
No. 1	.25	.75	.38
No. 2	.38	1.125	.50

Wood Characteristics

The primary analysis separated those studs completely free of any pith (Group 1) from others containing the pith (Groups 2 and 3). Figure 4 shows the means and ranges for crook in these three groups. Seventy-nine percent of the pith-free studs remained straight (within National Grading Rule limits) throughout drying and during post-test storage, as may be seen in table 1. These pith-free studs included those in Group 4 purposely processed as true flat-sawn and those in Group 5 which were true quarter-sawn. Provided the pith is completely removed in sawing, it appears to make no difference in crooking whether studs are flat-sawn or quarter-sawn. Both the flat- and quarter-sawn groups had a high percentage of studs within the National Grading Rule limitations for all three types of warp. Mild compression wood, which occurred only in short discontinuous streaks in Group 1 studs, appears to cause little if any crooking in pith-free studs.

In contrast to the pith-free studs in Group 1, warping in the studs containing pith (Groups 2 and 3) varied considerably. The individual maximum amounts ranged from 0 to 1.60 inches in crook, 0 to 1.70 inches in bow, and 0 to 0.82 inch in twist. Such wide ranges in warping prompted further examination of these latter two groups. Subsequently, the thin cross sections of all studs containing pith were examined for compression wood on the lamp table. Of the 82 studs examined with this technique, 29 percent were found to

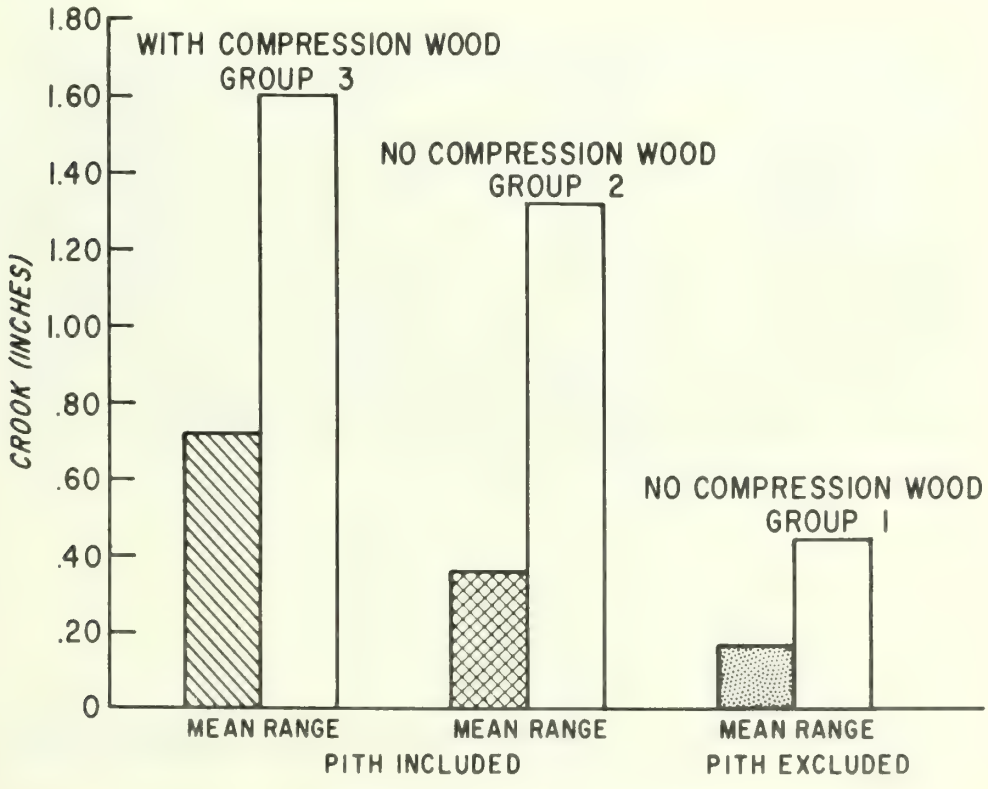

Figure 4.— Variation in crook for three groups of pine studs.

have significant amounts of mild compression wood in the first three annual rings for at least half the stud length. It should be noted that this compression wood in the early years of growth was not apparent in the initial visual examination and selection of these studs for study. Examples of severe and mild compression wood are shown in figure 5.

Mild compression wood in the pith area of a high percentage of the studs containing pith was not the only cause for their large variation in warping. As may be seen in figure 4, the range in crook of studs with pith but without significant compression wood in the initial annual rings (Group 2) was almost as wide as the range of those with compression wood in the pith area (Group 3), although the mean crook for Group 2 (0.36 inch) was only half that of Group 3 (0.72 inch). The cause for excessive variation was not determined. Consequently, predictions about the likelihood of severe crook of studs containing pith, with or without compression wood, will probably be highly unreliable at present.

The direction of warping in individual studs containing pith can usually be predicted from the position of the pith, compression wood, and knots. For instance, it is generally believed that crook or bow occurs along the face or edge closest to the pith and that the stud will crook if the pith is nearest the edge or bow if the pith is nearest the wide face. This tendency stems from the greater longitudinal shrinkage expected in the region surrounding the pith. In this study, however, warping was sometimes greater on the opposite face or alternated several times before the stud reached an apparent equilibrium condition. This characteristic was observed only with free-hanging studs (Group 9).

Moisture Content

All warping was directly related to decreasing moisture content; crook increased sharply when the studs reached the general range of the fiber saturation point (25 to 35 percent moisture content), as illustrated in figure 6. Measurable warping occurred within the first 4 days, at which time the mean moisture content was usually in excess of 40 percent. Measurable shrinkage in cross-section dimensions preceded measurable warping by several days. Of special interest was the amount of crooking which had taken place in drying from the green condition to 19 percent moisture content, the maximum allowed by the

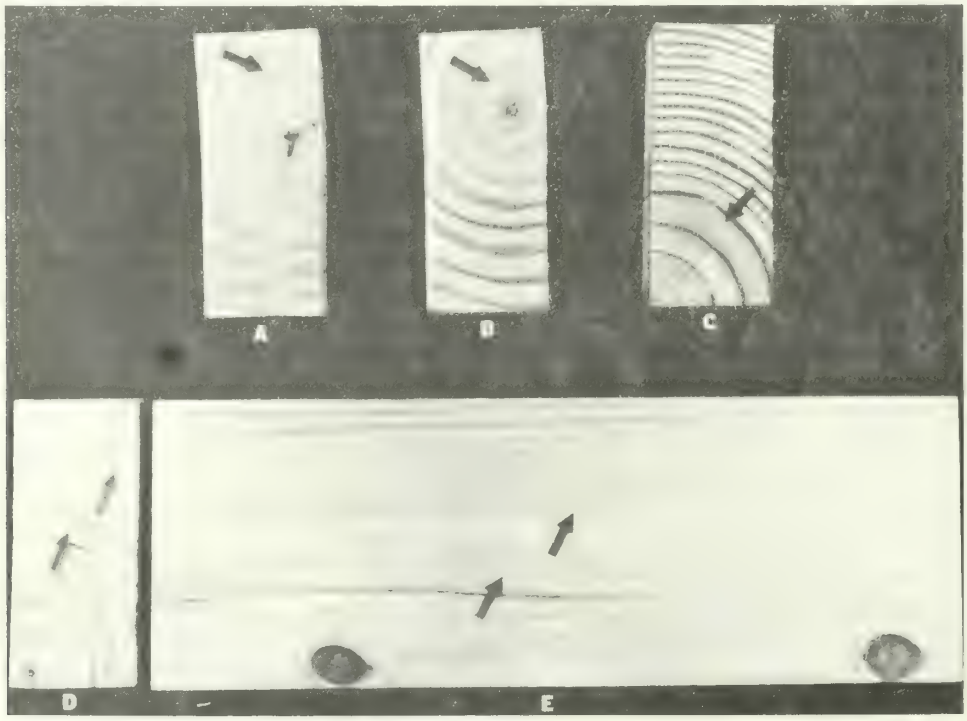

Figure 5.—Cross sections of studs with mild (A, B, C, above) and severe (D, below) compression wood. Block E is side view of cross section D.

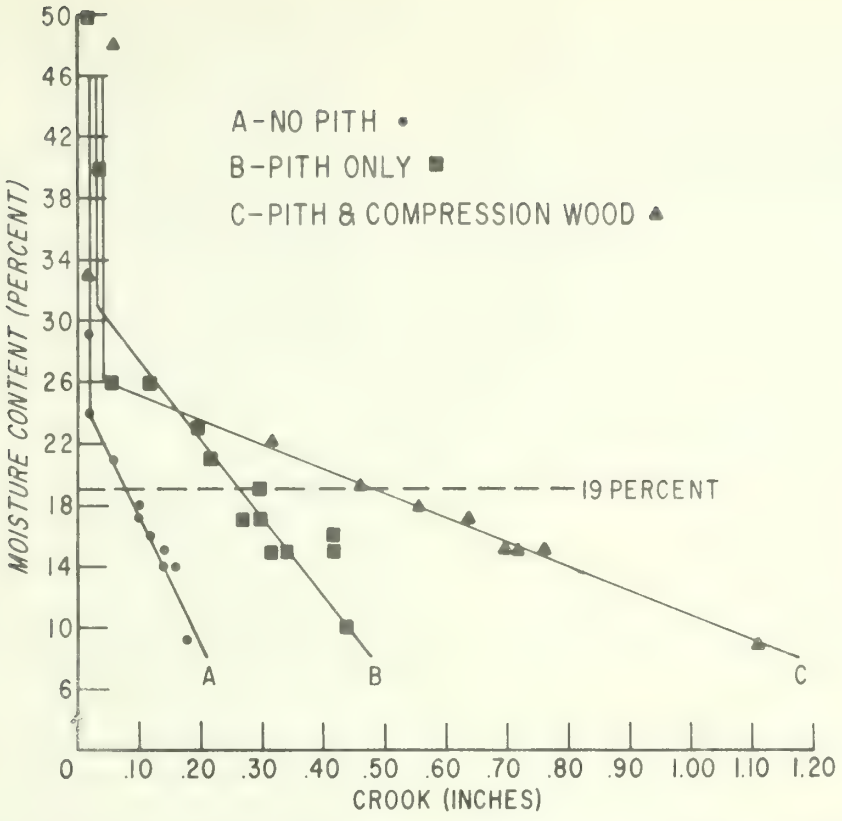

Figure 6.—Relationship of crook to moisture content during air drying for three individual studs representative of the types indicated. The dashed line indicates the maximum moisture content allowed by the current National Grading Rule for air-dried studs.

current National Grading Rule. As seen in figure 6, only 50 to 60 percent of the total crook in each stud had occurred by the time the stud had dried to 19 percent. The additional 40 to 50 percent of the total crook in each stud occurred during the period when the moisture content dropped from 19 percent to the termination point of 10 percent. Pith-free studs showed little change in crooking in relation to moisture content after drying to 10 percent. Studs containing the pith continued to crook as long as stud moisture content was decreasing and for a period after moisture content reached a plateau at the 10-percent level. The rate at which crook changed, as well as the rate of change for other forms of warp, was considerably greater for studs containing the pith than for pith-free studs.

As noted, the present National Grading Rule calls for a maximum moisture content of 19 percent for air-dried and 15 percent for kiln-dried studs. Although the average moisture content of each type would be slightly lower, even one stud that shrinks excessively can cause several problems in a wall. This study shows that, under the current National Grading Rule, a stud containing pith might pass inspection for 3/8-inch allowable crook at 19 percent moisture content and then crook as much again after it is placed in use. Suggested solutions are drying to a lower moisture content before grading for crook or reducing the allowances for crook at 19 percent moisture content. Neither of these practices would be palatable to the industry, but problems developing from warped studs are also unpalatable to the homeowner.

Warping in response to changes in equilibrium moisture content (E.M.C.) during drying can vary with different types of studs because each varies in wood characteristics, particularly in longitudinal shrinkage. Warping increases at low E.M.C. and can be arrested, or lessened, with upward changes in E.M.C. Studs containing pith are likely to exhibit excessive longitudinal shrinkage, which can in turn cause greater warping than exhibited by pith-free studs. An example of this response to changes in E.M.C. by two individual studs (one with and one without pith but

both without compression wood) is shown in figure 7. The largest changes in warping can be expected when stud moisture content is in the range from 19 to 10 percent. The studs shown in figure 7 were at 28 percent moisture content on the 2nd day, 19 percent on the 5th day, and 10 percent on the 18th day. An upward change in E.M.C. (from point A to point B) caused an abrupt decrease in crooking of the stud containing pith; a downward change in E.M.C. (from point B to point C) brought about a return in increased crooking. Similar responses were exhibited only slightly by the pith-free stud, indicating its stabilty. For the homeowner, such changes during different seasons of the year create problems that cannot be corrected once and for all.

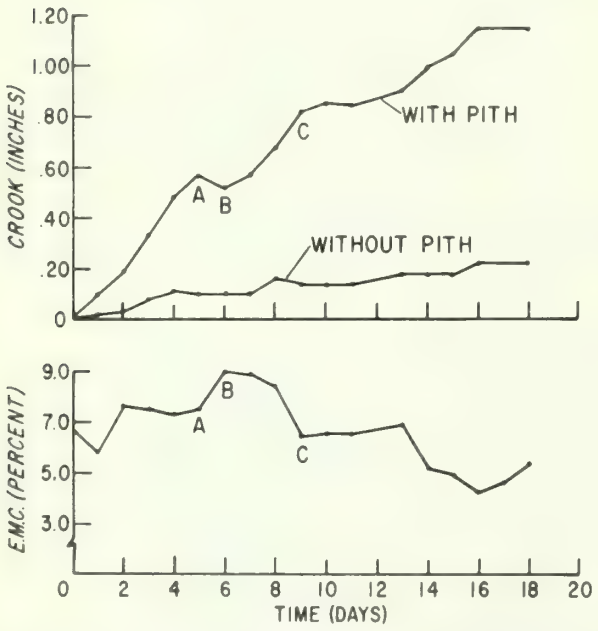

Figure 7.—Crooking of two individual studs (one with and one without pith but both without compression wood) during air drying from the green condition to 10 percent moisture content (above) and actual equilibrium moisture content (E.M.C.) of air during drying (below). Points A, B, and C have been inserted on the two graphs for comparison.

CONCLUSIONS

Several general points can be made about the warping characteristics of all 120 studs evaluated in this study. On the average, bow and crook occurred in approximately the same amount, although crook is the more severe type of warp. The difficulty of straightening a crooked stud in contrast to a bowed one is recognized in the National Grading Rule by permitting three times as much bow as crook in the same stud. Twist is the least severe type of warp and is probably more easily restrained by conventional fastening methods than crook or bow.

Warping characteristics were similar in pairs of studs resawn from the same square cants (Group 6) or the same 2-inch-thick pieces of dimension 8 or more inches wide and containing pith in one or both of the studs (Group 7). The similarity expected in crooking of such matched pairs was upheld by a statistical t test at the 5-percent level; bow and twist in matched pairs were not tested statistically for similarity but would also be expected to be alike.

When mean values were compared, toenailing or other fastening methods used in conventional construction appeared to have some restraining effect on bowing and crooking. However, studs restrained during testing (Group 8) ranged as much in bow and crook as did the free-hanging studs (Group 9). As might be expected, restraint by nailing had a much greater beneficial effect on twisting than on either bowing or crooking.

Several major conclusions pertaining specifically to second-growth southern pine but also likely to apply to other softwood species whose second-growth is used in construction may be drawn from this study:

1. Studs which contain pith, in part or completely, are prone to warp considerably in excess of current National Grading Rule limitations.

2. To a large extent, warping problems are associated with the presence of mild compression wood in the first three or four annual rings surrounding the pith for one-half or more of the stud length. This mild compression wood is not readily visible to the naked eye. Studies of mild compression wood in softwood lumber should be initiated to determine its causes more positively and to provide information leading to easy detection and remedies.

3. Studs may warp as much in the wall, where their moisture content may go from 19 percent to 10 percent or less, as they did in drying from the green condition to 19 percent. The maximum allowance of 19 percent moisture content as set forth in the current National Grading Rule is too high for residential construction, particularly when studs containing the pith are used. Environmental changes may lower the moisture content of the stud in place to 10 percent or less, with resultant further warping.

Gaby, L. I.
1972. Warping in southern pine studs. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-96, 8 pp.

Measurement of warping, shrinkage, and moisture content of southern pine 2 by 4 studs during drying in the laboratory from the green condition to 10 percent moisture content indicated that (1) studs containing no pith exhibited the least warp and easily met grading standards, (2) studs containing pith warped approximately twice as much as pith-free studs, and (3) studs containing pith with mild compression wood warped most of all. Warping in the latter two types exceeded limitations set by current grading standards. Approximately half of the measured warping occurred after studs dried below 19 percent. Limited use of studs containing pith, a lowered maximum moisture content for studs, and stricter restrictions on warping in relation to moisture content are discussed.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

ISDA Forest Service Research Paper SE-97 June 1972

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timating Recreational Use at Developed Observation Sites

by

George A. James

and

Anthony K. Quinkert

neastern Forest Experiment Station - Asheville, North Carolina U.S. Department of Agriculture - Forest Service

Cover depicts Pikes Peak, elevation 14,110 feet above sea level, as viewed from Wilkerson Pass Wayside on the Pike National Forest in Colorado.

Estimating Recreational Use at Developed Observation Sites

by

George A. James, Principal Recreation Specialist
Asheville, North Carolina

and

Anthony K. Quinkert, Recreation Staff Officer
Pike National Forest
Colorado Springs, Colorado

Developed observation sites are designed so that the public may view outstanding scenery. Such sites are generally only a few acres in size and range from a simple turnout where vehicles may pull off the main highway to those located along heavily used travel routes and often containing picnic tables, comfort stations, small visitor information buildings, and other facilities. The Forest Service currently maintains and operates 412 observation sites. In addition, several thousand are operated and maintained by other Federal, State, and municipal agencies.

Although the length of stay at most observation sites may be only 10 minutes or less, these sites are of special significance to recreation managers and planners. Their primary purpose is to present the traveler with an awe-inspiring spectacle and perhaps, for a fleeting moment at least, to provide him with a feeling of tranquillity and spiritual uplift. For staffing, maintenance, and cleanup purposes, it is essential that recreation managers be knowledgeable of the amount and timing of use at these sites.

Sampling techniques have been designed and tested for estimating recreational use on a wide variety of sites and areas,[1] [2] but none can be used effectively without modification for observation sites. The principal difficulty in estimating recreational use on these sites is the short length of stay of visitors.

[1] James, George A. Recreation use estimation on Forest Service lands in the United States. Southeast. Forest Exp. Stn., U. S. Forest Serv. Res. Note SE-79, 8 pp. 1967.

[2] James, George A., and Taylor, Gordon D. Recreation use estimation in the United States and Canada. XIV. IUFRO-Congr. Proc. Vol. VII (Sect. 26) Munich. 1967: 14-29. 1967.

In an effort to provide recreation managers and planners with a useful sampling procedure for this purpose, a pilot study was made during the summer of 1970 on the Wilkerson Pass Wayside, Pike National Forest, in Colorado. The Wayside, which sits atop the 9,507-foot summit of Wilkerson Pass on U.S. Highway 24, 50 miles west of Colorado Springs, provides a panorama of the surrounding country, including Pikes Peak to the east and South Park to the west. It has parking facilities for approximately 50 vehicles, comfort stations, picnic tables, an observation platform, a covered walkway where exhibits are displayed, and a small visitor information service (VIS) building containing a large relief map of the area (fig. 1). Brochures, maps, and historical information are also made available by the attendant on duty. During the 1970 summer season, the building was manned from 9:30 a.m. to 5:30 p.m. daily.

Techniques and Procedures

The principal objective of the study was to determine the amount and timing of use so that management might select the most effective period of the day when the VIS building should be staffed to accommodate the maximum number of visitors and the best schedule for cleanup and maintenance of the site. The sampling study covered the period from May 28 through September 8, 1970, during which a stratified random sampling model was used to obtain estimates of use. Stratification included time of day and day of week. For time-of-day strata, the period from 9:30 a.m. to 5:30 p.m. was divided into four 2-hour periods: 9:30 a.m. to 11:30 a.m., 11:30 a.m. to 1:30 p.m., 1:30 p.m. to 3:30 p.m., and 3:30 p.m. to 5:30 p.m. For day-of-week strata, days were divided into weekdays (WD) and those falling on week-

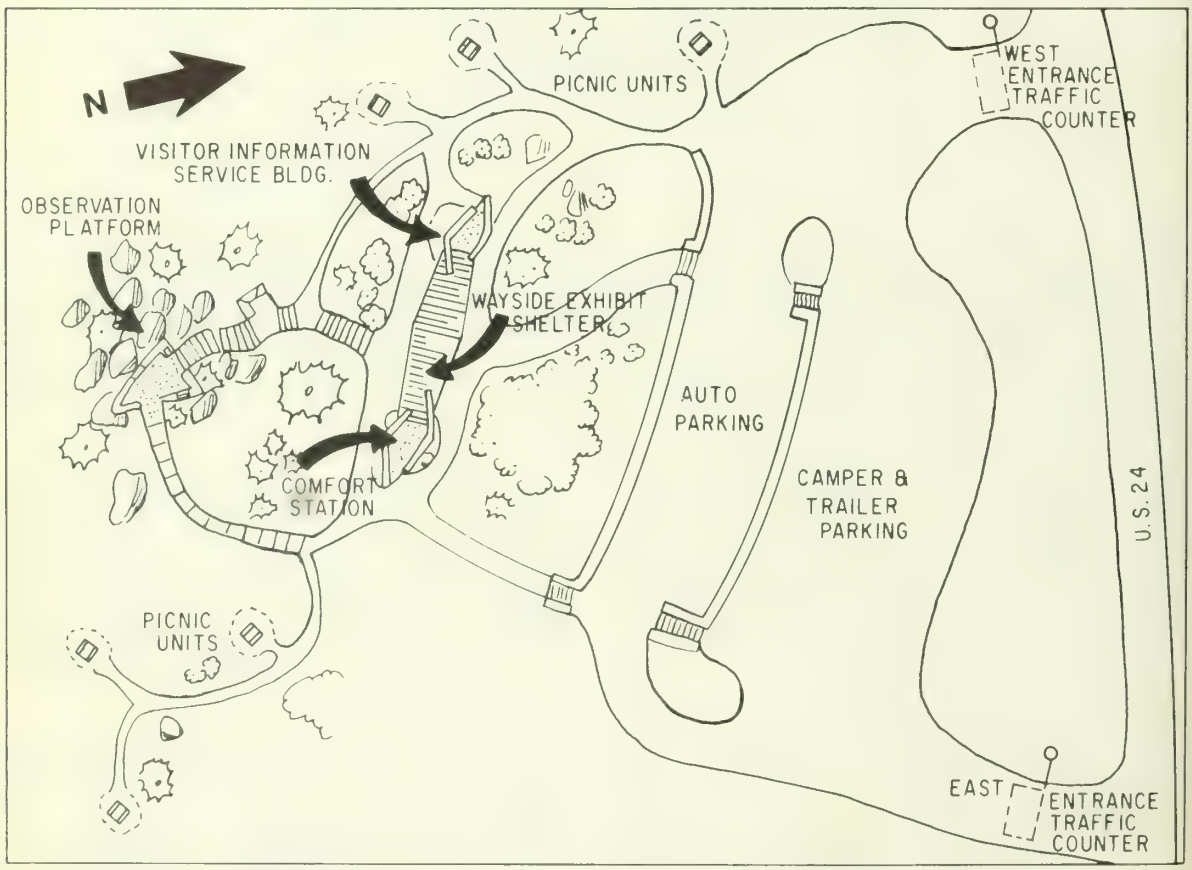

Figure 1. — Wilkerson Pass Wayside on the Pike National Forest, 50 miles west of Colorado Springs, Colorado.

ends and holidays (WE/H). Each weekday time-of-day stratum was sampled seven times; each weekend/holiday time-of-day stratum was sampled five times. Forty-eight sampling units were used, as summarized below:

Day of week	Time of day	Sampling opportunities *(number)*	Sampling units *(number)*
WD	9:30-11:30	71	7
WD	11:30-1:30	71	7
WD	1:30-3:30	71	7
WD	3:30-5:30	71	7
WE/H	9:30-11:30	33	5
WE/H	11:30-1:30	33	5
WE/H	1:30-3:30	33	5
WE/H	3:30-5:30	33	5

Variables for which estimates were desired and sample information obtained included:

1. Number of visits to Wayside, by time of day and by day of week
2. Mean number of persons per vehicle
3. Mean length of stay per visitor
4. Total visitor-days of use during season
5. Total number of vehicles traveling U.S. Highway 24, by direction of travel
6. Percentage of vehicles traveling U.S. Highway 24 that stopped at Wayside, by direction of travel
7. Total number of vehicles stopping at Wayside
8. Total number of visits to VIS building
9. Percentage of visitors stopping at Wayside who also visited VIS building
10. Origin of visitors (from vehicle license plates).

Vehicle counts were obtained mechanically during the season. Linear regression procedures were used to establish relationships between use and traffic so that these estimates might be updated in future years. For this purpose, magnetic-loop, printout-type counters were installed at both entrances to the site in order to obtain an hourly record of all vehicles entering and leaving.

Except for the attendant who counted the number of visits to the VIS building, one observer was able to collect all of the sampling information during each 2-hour sampling period. Approximately 10 minutes before the sampling period began, the observer recorded a general description of each vehicle in the parking lot, including the state and (for Colorado residents) county of registration. He also recorded traffic-counter readings at the beginning of the period.

When the period began, the observer stationed himself so that he could observe all vehicular traffic along U.S. Highway 24 and all vehicles and persons entering and exiting the parking lot. Total number of vehicles traveling U.S. Highway 24 and number of vehicles entering the site, by direction of travel, were recorded. For each entering vehicle, the observer recorded number of people, time of entry to nearest minute, and a brief description of each vehicle to aid in identifying it upon departure. The time, to the nearest minute, that each vehicle departed the site was also recorded. At the end of the period, the observer again recorded the traffic-counter readings and also obtained the count of visitors to the VIS building from the attendant.

Analysis and Results

Estimates of total number of visits during the season and associated standard errors were generated from the simple linear regression and stratified random-sampling procedures to determine how closely the estimates derived from the two procedures agreed. For regression analysis, number of visits to the site during each sampling period were regressed separately on readings from the traffic counters at the east and west entrances, and on the reading from both counters combined, during the same 2-hour period. The more precise estimate was obtained with the record from the west entrance. Stratified random sampling was used to generate estimates of use for all other variables. All estimates produced by stratified random sampling were highly accurate. Estimates

of use and associated standard errors for all variables are presented in table 1.

The estimates of number of visits as generated by stratified random sampling and linear regression procedures agreed closely. However, because relationships between number of visits and the traffic-count record at the west entrance were strong and would thus provide a means of updating estimates of visits in future years, the regression procedure was selected in preference to stratified random sampling. The regression formula for generating estimates of number of visits during the season is shown below:

$$Y = a(N) + b(X)$$

where Y is the number of visits between 9:30 a.m. and 5:30 p.m. throughout the 104-day season, a and b are constants, N is the number of sampling opportunities available, and X is the season-long reading from the counter at the west entrance between 9:30 a.m. and 5:30 p.m. Solving of the equation generated the following estimate for visits throughout the season:

$$Y = 62.58(416) + 1.46(36,357) = 79,114$$

By substituting appropriate vehicle counts into the regression equation, estimates of number of visits were generated for hour-of-day strata, day-of-week strata, and for each month (table 2). For purposes of estimating use over the next several years, it is assumed that relationships between number of visits and the traffic-count record at the west entrance will remain unchanged and also that the average value of all other variables will not change.

Total use in visitor-days and mean length of stay per visitor could not be simply calculated because visitor selection was inversely proportional to the visitor's length of stay. Appropriate computational procedures were used to produce estimates

Table 1. — Estimates of recreational use at Wilkerson Pass Wayside, Pike National Forest, Colorado, from May 28 through September 8, 1970

Variable	Use estimate[1]	Standard error[2]
Visits to Wayside (number)	78,567	±5.0
Visits to Wayside (number)	[3]79,114	±3.1
Mean number of persons per vehicle	2.97	±1.5
Mean length of stay per person (minutes)	17.9	±3.8
Visits to VIS building (number)	23,863	±1.1
Persons stopping at Wayside who visited VIS building (percent)	[4]29.0	
Westbound vehicles stopping at Wayside (percent)	21.0	
Eastbound vehicles stopping at Wayside (percent)	22.0	
Total visitor-days of use at Wayside	2,147	±7.0

[1]Unless otherwise noted, all estimates were generated by stratified random-sampling procedures.
[2]Standard error expressed as percentage of the estimate.
[3]Generated by linear regression based on relationship between number of visits and record from traffic counter at west entrance between 9:30 a.m. and 5:30 p.m. Stratification was ignored in producing this estimate.
[4]Estimate derived by dividing total number of visits to Wayside into total number of visits to VIS building.

Table 2. — Regression estimates of number of visits by month, time of day, and day of week at Wilkerson Pass Wayside, Pike National Forest, Colorado, from May 29 through September 8, 1970[1]

Time	May[2]		June		July		August		September[3]		Total	
	WE/H	WD	WE/H	WD	WE/H	WD	WE/H	WD	WE/H	WD	WE/H	WD
9:30-11:30	526	3,488	1,721	5,171	2,460	4,082	2,238	730	572	13,471	7,517	
11:30-1:30	538	3,580	1,768	4,930	2,565	4,149	2,227	768	702	13,427	7,800	
1:30-3:30	503	3,632	1,920	4,581	2,720	3,784	2,408	765	683	12,762	8,234	
3:30-5:30	459	2,644	1,569	3,228	1,969	2,868	1,819	701	643	9,441	6,459	
Total	2,026	13,344	6,978	17,910	9,714	14,883	8,692	2,964	2,600	49,101	30,010	

[1]WE/H = days falling on weekends and holidays; WD = weekdays.
[2]Includes only May 29 through 31.
[3]Includes only September 1 through 8.

nd standard errors for these variables.[3] otal use was calculated to be 2,147 visitor-ays, with an average length of stay per isitor of 17.9 minutes (table 1).

One disadvantage of the sampling pro-edure used was that visitors who stayed onger than 2 hours on the site would be utomatically excluded because each ampling period was only 2 hours long. his was not a problem in our study, how-ver, because no visitors stayed longer an 2 hours, and only 0.1 percent stayed etween 90 and 120 minutes. However, n future sampling efforts in which visitor election is inversely proportional to the isitor's length of stay, it will be necessary at the sampling period used be long nough to insure that most visitors remain or periods that are shorter than the length f the sampling period.

Information obtained from vehicle cense plates revealed that 56 percent of ne vehicles stopping at Wilkerson Pass Vayside were from outside the state. Of ne vehicles having Colorado license plates, ost came from counties within 2 hours' riving time from the Wayside.

[3] Formulas for computing estimates and standard rors are available upon request from the South-stern Forest Experiment Station, P. O. Box 2570, sheville, North Carolina 28802.

Discussion

The sampling technique yielded precise estimates of current use and a procedure for updating estimates in future years on the basis of an easily obtained indicator of use. Estimates concerning the magnitude, characteristics, and timing of use will provide the basis for improving the staffing and servicing of the Wayside and facilities. Discovery that only one in every five vehicles traveling U.S. Highway 24 stops at the site, and that of those that do stop only three of 10 visit the VIS building, may indicate the need for efforts to increase visitation rates, perhaps by improving and adding signs along the main highway and within the site. Information that over half of all visits to the Wayside are made by persons from outside the state will aid decisions as to the type of displays, brochures, and other material to prepare and disseminate at the VIS building.

Total cost of the sampling effort was approximately $1,100, including $450 for the sampling phase, $50 for overhead, and approximately 60 hours for data analysis and report preparation. To this must be added the cost of a traffic counter which must be used at the Wayside for several years. The magnetic-loop, printout-type counter used during the calibration phase cost $650, but it can now be replaced with a totalizing counter costing only $200. The

strong relationship between number of visits and the traffic pattern at the west entrance makes it possible to update estimates for several years after calibration. If the study cost of $1,300 is prorated over a 5-year period, annual cost is approximately $260. For the next 4 years, the only information needed to update estimates of use is an accurate traffic-counter record for the period May 28 through September 8.

The technique can be further improved and costs reduced in future sampling efforts by obtaining rough advance estimates of use and its variability. In the case of Wilkerson Pass Wayside, such advance estimates could have been obtained quite inexpensively by installing a printout-type traffic counter on the site 1 year prior to sampling. The traffic-count record could have been used to construct meaningful strata and to determine sampling intensities needed in each stratum to reach specified levels of precision. Failure to obtain this information prior to 1970 resulted in an intensity and cost of sampling that were greater than necessary and a sampling frame that did not include all of the important periods of use.

For example, an advance estimate of use and variability at Wilkerson Pass Wayside would have revealed the considerable uniformity in visitation rates within strata and would have indicated that fewer sampling units were necessary than were used. In addition, a 1969 traffic-count record would likely have shown considerable visitation at the site beginning as early as 7 a.m. and continuing until approximately 8 p.m. Without this advance knowledge, sampling in 1970 was concentrated in the period from 9:30 a.m. through 5:30 p.m. The season-long traffic count during this period, on which estimates of use were based, was 36,357 vehicles. However, the season-long traffic count during the "overnight" period from 5:30 p.m. through 9:30 a.m. was 16,444. Forty-three percent of this additional use occurred from 7 a.m. to 9:30 a.m., and 37 percent occurred from 5:30 p.m. to 8 p.m. Light sampling was needed in two additional hour-of-day strata to obtain estimates for these early- and late-use periods. These records indicate that perhaps the VIS building should be manned during more hours of the day in order to accommodate a greater number of visitors.

Recommendations

Wilkerson Pass Wayside presented a complex sampling situation. The sampling technique worked well and can be recommended for use at other observation sites and similar developments where one person can observe all entering and exiting vehicles and visitors. It is recommended that advance estimates of use be obtained to ensure sound sampling procedures, especially on sites that are heavily used. When use estimates are desired on small observation sites, light sampling to determine average number of persons per vehicle and average length of stay per person, coupled with an accurate, season-long vehicle count, can be expected to provide acceptable estimates of use at low cost.

U. S. GOVERNMENT PRINTING OFFICE: 1972 — 747-089 / 6203

James, George A., and Quinkert, Anthony K.
1972. Estimating recreational use at developed observation sites. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-97, 6 pp.

On the Pike National Forest in Colorado during the summer of 1970, stratified random sampling of the timing, number, and origin of visitors and simple linear regression based on the relationship between traffic-count records and number of visitors were successfully used to estimate recreational use at Wilkerson Pass Wayside, an observation site containing a 50-car parking lot, comfort stations, picnic tables, an observation platform, and a small building for visitor information service (VIS). This sampling technique, which involves a single observer and can be used at other observation sites, provides the basis for improving the staffing and servicing of the facility and for updating estimates in future years because of the strong relationship found between use and the traffic-flow pattern.

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USDA Forest Service Research Paper SE-98 August 1972

Vapor Barrier Decreases Moisture Conditions in Wood Walls Exposed to Air Conditioning and Heating

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Vapor Barrier Decreases Moisture Conditions in Wood Walls Exposed to Air Conditioning and Heating

by
J. E. Duff, Associate Wood Scientist
Forestry Sciences Laboratory
Athens, Georgia

INTRODUCTION

The modern wood-frame home is characterized by well-insulated walls to increase the heating and cooling efficiency. Because insulation reduces the flow of heat through the wall, it causes a local increase in the steepness of the temperature gradient across the wall section. This temperature gradient can lead to moisture accumulations in the wall during both winter heating and summer air conditioning. During winter, the amount of water vapor that accumulates in the interior of the wood-frame structure is substantially greater than the amount of moisture present in the exterior air. This difference gives rise to a strong vapor pressure gradient that causes the interior water vapor to migrate through the wall toward the outside. As the moisture vapor cools because of the decreasing temperature gradient in the wall, the relative humidity of the vapor and air mixture increases drastically. If the relative humidity reaches 100 percent, liquid moisture will condense and be absorbed by the structural components in the wall, an undesirable result. A similar situation can occur in an insulated wall during summer air conditioning, when the flow of water vapor is reversed.

The obvious solution to the problem of moisture accumulations in insulated walls is to provide a vapor barrier to prevent the water vapor from flowing through the wall. Research as well as experience have shown that, when a vapor-resistant material is placed on the warm side of the insulation to prevent mass moisture flow into the wall during winter heating, the wall remains essentially dry.[1] [2] Conversely, when a vapor barrier is placed on the outside of the insulation for summer air conditioning, the wall will remain dry.

[1]Teesdale, L. V. Condensation problems in modern buildings. USDA Forest Serv. Forest Prod. Lab. Rep. 1196, 18 pp. 1959.

[2]Duff, J. E. Moisture distribution in wood-frame walls in winter. Forest Prod. J. 18 (1): 60-64. 1968.

When an insulated wall is exposed to both winter heating and summer air conditioning, however, legitimate questions arise concerning the correct position of the vapor barrier. Obviously, the correct placement of the vapor barrier for winter heating is incorrect for summer air conditioning. The severity of the moisture accumulation in a wall with an interior vapor barrier depends on how warm the summer environment is. Previous work has shown that, in areas requiring only moderate air conditioning because the outside ambient temperature drops below the interior temperature at night, high accumulations will occur in such walls only at night.[3] However, it is assumed that, in areas with extremely hot, humid summers during which the outside ambient temperature remains above the interior temperature, hazardous accumulations of moisture (20 percent or greater) would persist in such walls over long periods, although this conclusion can be verified only after more extensive study.

During winter heating, the use of insulated walls with exterior vapor barriers could result in hazardous moisture accumulations if the winter is severe. Extremely cold winters cause large amounts of water vapor to migrate into the wall and subsequently condense. Actually, the exterior vapor barrier increases the hazards of moisture condensation during winter because such barriers prevent the wall from drying from the outside. Under these conditions, liquid moisture accumulates rapidly in the insulation cavity and gives rise to serious decay hazards and potential problems with paint deterioration. It is believed that mild winters (no sustained cold weather below 32° F.) would not result in significant moisture accumulation if exterior vapor barriers were used, although this conclusion requires confirmation.

Fortunately, in geographical areas where extremely cold winters exist, the duration of the hot summer weather is short; and, in areas where the summers are long and hot, the winters are not severe. Consequently, the proper position of the vapor barrier in walls subjected to these extreme conditions can be easily determined. It is in regions where summer air conditioning and winter heating are used equally that the choice of position of the vapor barrier is not so obvious.

The present study was undertaken to determine how the position of the vapor barrier or lack of a barrier affects the moisture conditions in an insulated stud wall when summer air conditioning and winter heating are used about equally. Emphasis was placed on the amount and duration of moisture in the wood studs, exterior sheathing, and wood siding over a 12-month period and on how direction of exposure affects moisture accumulations.

MATERIALS AND METHODS

Environmental Exposure Structure

This study was conducted at the Southeastern Forest Experiment Station's Whitehall environmental structure in Athens, Georgia (fig. 1). The 24- by 24-foot structure contains removable 4- by 8-foot sections in each exterior wall; each exterior wall faces a different cardinal direction. The structure is located in an open area unshaded by trees and other structures.

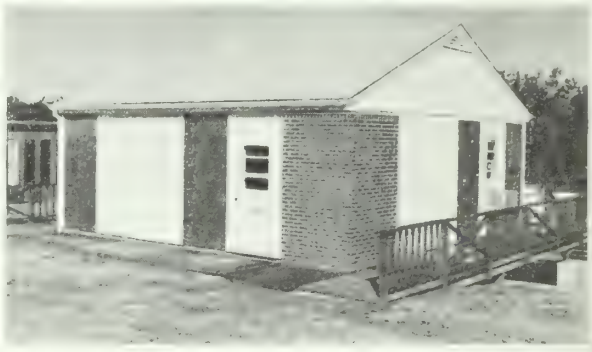


Figure 1. — Whitehall environmental exposure structure at Athens, Georgia.

Experimental Panels

The 4- by 8-foot wall sections used in this study each consisted of three 16-inch by 8-foot study panels. Each wall section consisted of four 2- by 4-inch studs approximately 16 inches on center, an outer sheathing of ¾ inch insulated fiberboard, and 3-inch fiberglass batt insulation (without vapor barrier). A 0.006-inch polyethylene vapor barrier was stapled to the inside surface of the studs of the first wall panel and on the outside surface of the second wall panel (fig. 2). The third panel did not contain a vapor barrier.

Duff, J. E. The effect of air conditioning on the moisture conditions in wood walls. Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Pap. SE-78, 8 pp. 1971.

The interior surface of the wall section was covered with ½ inch gypsum board painted with two coats of interior latex paint, and the exterior surface of the wall section was covered with conventional beveled lap siding and painted white with an exterior latex-based paint. The sheets of exterior sheathing and interior gypsum board were continuous over the entire 4-foot width of each section.

Moisture and Temperature Measurement

Wood moisture probes were used to measure moisture content at selected points in the 12 study panels. Each probe consisted of a small strip (0.07- by 0.07- by 0.75-inch) of hard maple.[4] The two tangential surfaces were painted with conductive silver paint. Moisture content was indirectly measured as a function of the electrical resistance of the wood between the two silver electrodes.

The temperature of each probe was recorded by a copper-constantan thermocouple adjacent to the probe. Both the moisture probes and the thermocouples were installed at mid-height in the cross-sectional centers of the study panels during their fabrication (fig. 2). Moisture probes for the studs were installed only in the geometric centers of the two outer wood studs adjacent to the first and third study panels. The lead wires from all sensors were routed to the top of each study panel and connected to the automatic data collection system, where the measurements were recorded on punched paper tape. The 1,000-foot punched data tapes were read into the 1401 and 7094 IBM computers, which computed temperatures and moisture contents corrected for temperature and then plotted the calculated data for analysis.

[4]Duff, J. E. A probe for accurate determination of moisture content of wood products in use. Forest Prod. Lab., U. S. Forest Serv. Res. Note FPL-0142, 10 pp. 1966.

Experimental Procedure

The interior of the Whitehall test structure was heated and air-conditioned to 75° F. ± 3° F. with an electric heat-pump air conditioner. During winter heating, the interior humidity was maintained at 30 percent ± 5 percent with an automatic humidifier. During summer air conditioning, no attempt was made to control the interior humidity. This building was unoccupied during the study, except for those who made occasional measurements, and contained no plumbing facilities to influence moisture conditions inside the structure.

Collection of data began in August 1968 and continued at 6-hour intervals during the 12-month study. The study was terminated in August 1969.

Data Analysis

Over 1,000 observations were recorded from each moisture sensor. After all observations had been plotted by the computer, the maximum monthly moisture contents were selected and plotted against time. This approach for summarizing the

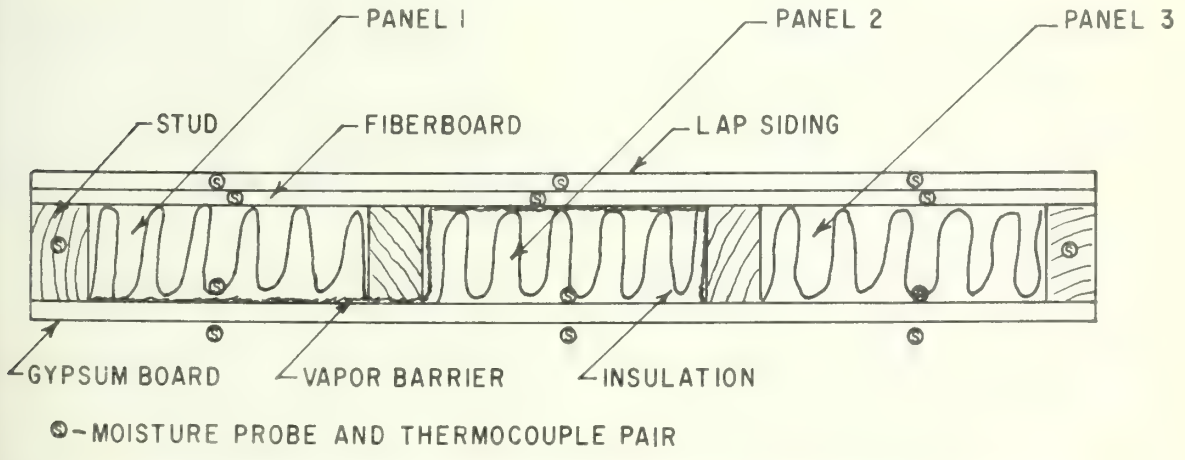


Figure 2. — A horizontal cross-sectional view of the three types of study panels. Note the positions of the moisture and temperature sensors.

data was justified on the basis that a particular moisture plot based on over a thousand observations was practically identical to the moisture plot based on the maximum monthly values.

RESULTS AND DISCUSSION

Effect of an Interior Vapor Barrier

Figure 3 shows a yearly time plot of the moisture conditions in various structural components of the north-facing study panel with an interior vapor barrier. The north wall was selected because it was subjected to wider extremes of moisture than were the other three walls. As expected, the interior vapor barrier kept the moisture content of the exterior sheathing below 14 percent throughout the year and that of the siding below 16 percent during the winter. The interior moisture content of the wood stud remained below 11 percent throughout the year. After the peak moisture values were reached in February through April, the moisture content of all three structural components gradually dropped toward their lows of 10 to 12 percent with the approach of summer.

It is of interest to note that the equivalent moisture content of the sheathing was somewhat lower than that of the siding for most of the study, indicating that the exterior relative humidity was probably responsible for the slightly higher moisture content of the siding. The plot shows that

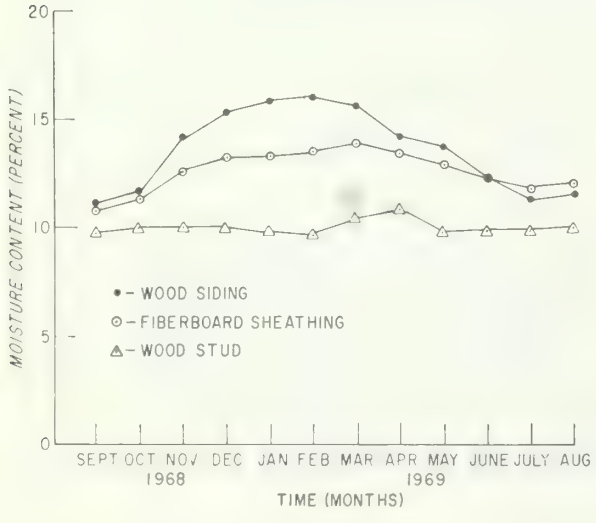


Figure 3. — Time plot of moisture conditions in the siding, exterior sheathing, and stud in the north-facing study panel with an interior vapor barrier.

summer air conditioning did not cause high moisture conditions in any of the wood components of the study panel. In fact, because of the improved drying conditions of summer, the moisture content of the siding was lower in summer than in winter.

Normally, if any major moisture condensation occurred, it would be measured near the interior vapor barrier. Figure 4 shows a time plot of the moisture conditions on the interior surface of the insulation of the same study panel. The moisture conditions during a 2-day period in March were low (7 percent) in comparison with those for 2 days in July. The high moisture values (23 percent) for July resulted from the wall's being heated by the exterior environment. The high moisture conditions were temporary, as shown, and are not considered hazardous (see footnote 3).

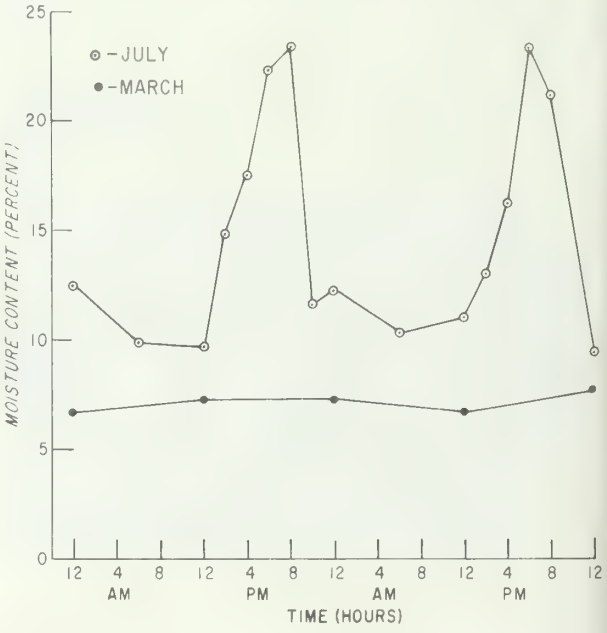
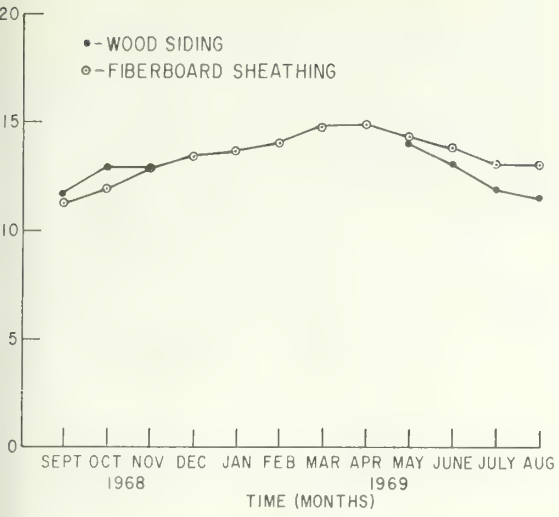


Figure 4. — Time plot of the moisture condition near the interior vapor barrier and interior insulation of a north-facing study panel for 2 days in March (March 1 and 2) and 2 days in July (July 28 and 29).

Effect of an Exterior Vapor Barrier

Figure 5 shows a yearly time plot of the moisture conditions in the siding and sheathing of the north-facing study panel with an exterior vapor barrier. This panel reacted almost identically with the north-facing panel with an interior vapor barrier. The maximum moisture content reached



ure 5. — Time plot of moisture conditions in the wood sid-ng and sheathing of the north-facing study panel with an xterior vapor barrier. (Winter data for the wood siding vere eliminated because of a recording error.)

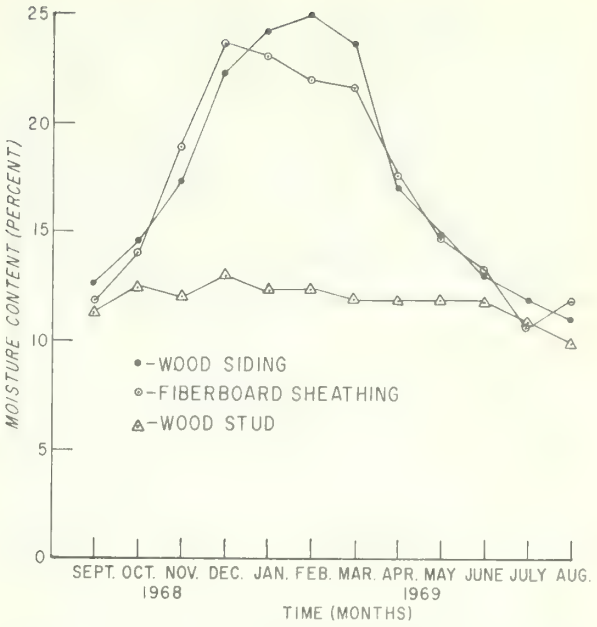


Figure 6. — Time plot of moisture conditions in the wood siding, sheathing, and stud of the north-facing study panel with no vapor barrier.

the sheathing was almost the same (15 percent). would appear that the position of the vapor rrier, whether inside or outside the insulation, s little effect on the moisture content of the eathing.

Unfortunately, a complete comparison of the ood siding for each of the two types of panels s not possible because a recording error elimi-ted all of the winter data for the moisture con-ions in the siding of the panel with an exterior rrier. However, the initial increase in moisture ntent of the siding in the latter panel was only ghtly higher (12 percent) than that for the siding the panel with an interior barrier (11 percent). rthermore, the decrease in moisture content of e siding followed about the same pattern for th panels. In both cases, the moisture con-nt of the siding decreased below that of the eathing with the arrival of spring. This steep cline was probably due to the warming of the rfaces of the siding with the onset of warm weath-: siding exposed to the exterior environment uld lose moisture faster than the unexposed eathing adjacent to it.

Effect of No Vapor Barrier

Figure 6 shows the moisture conditions in the ious components of the north-facing study panel without a vapor barrier. During the first month (September) of the study, the moisture content of the sheathing was approximately 12 percent, a value comparable with the moisture contents of the other two north-facing panels during that month. However, with the approach of cooler weather, especially cool nights, the moisture content of the sheathing started to rise rapidly. By early December, the moisture conditions in the sheathing exceeded 20 percent; and in late December the moisture content reached a peak of almost 24 percent. These moisture contents in excess of 20 percent continued during the winter months until April, when the sheathing began to dry out. It was not until July that the moisture content of the sheathing returned to its initial level of 11 to 12 percent.

The moisture content of the exterior siding followed the general rise and fall of moisture conditions in the sheathing — but with some notable exceptions. In the siding, moisture conditions peaked (25 percent) in February, 2 months later than in the sheathing. This delay was related to the fact that moisture responsible for the peaks moved through the sheathing first.

With the approach of warmer weather in April, the maximum moisture content of the siding

again coincided with that of the sheathing. Drying continued into summer, and in July — 1 month before the study was terminated — the moisture content of the siding returned to its initial level (10 to 12 percent). Again, the higher surface temperatures which improved drying conditions and reduced vapor flow through the wall during spring and summer were responsible for the decrease in moisture content of the sheathing and siding.

The moisture content of the stud in this study panel varied from a low of 10 percent to a high of 13 percent, and the moisture peak of the stud coincided with the peak moisture content of the sheathing. When the study panel started to dry out, the moisture content of the stud decreased to a value of 11 percent in July.

The great difference between the moisture contents recorded in the stud as opposed to those recorded in the sheathing and siding can be accounted for by the location of the moisture probe within the stud. The probe was located in the center portion of the wide face of the stud (fig. 2). This location is somewhat removed from the area of highest moisture concentration. It should be emphasized that, during the winter, the moisture conditions in a wall are in the form of an increasing gradient toward the outside. Hence, the center of the stud would not be expected to exhibit the high moisture conditions exhibited by the sheathing and siding. It can be assumed from the high moisture conditions in the sheathing that the exterior surface of the stud adjacent to it probably also reached moisture conditions in excess of 20 percent.

Effect of Direction of Exposure

No vapor barrier. — Figure 7 shows the moisture conditions in the exterior sheathing of the north-, east-, south-, and west-facing study panels with no vapor barriers. A comparison of the four moisture-time plots clearly indicates that direction of exposure had a definite effect on the maximum moisture contents reached by the sheathing in these panels. The east-facing panel reached the highest peak (25 percent), followed closely by the north-facing (24 percent) and the south-facing (23 percent) panels. The west-facing panel had the lowest peak (22 percent).

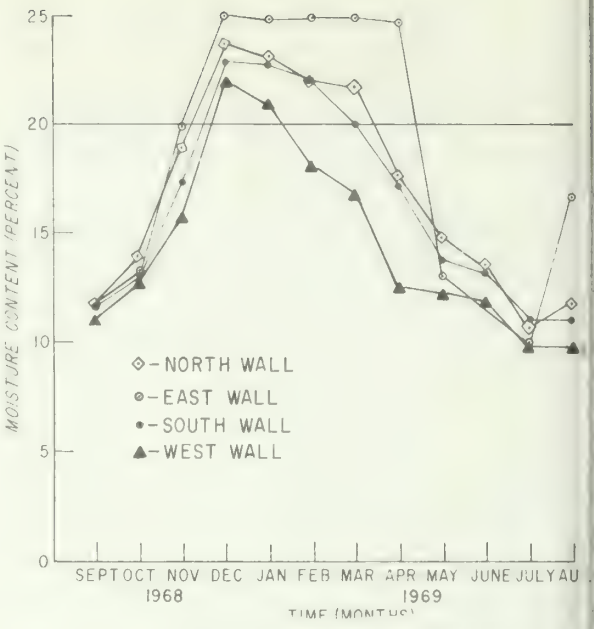
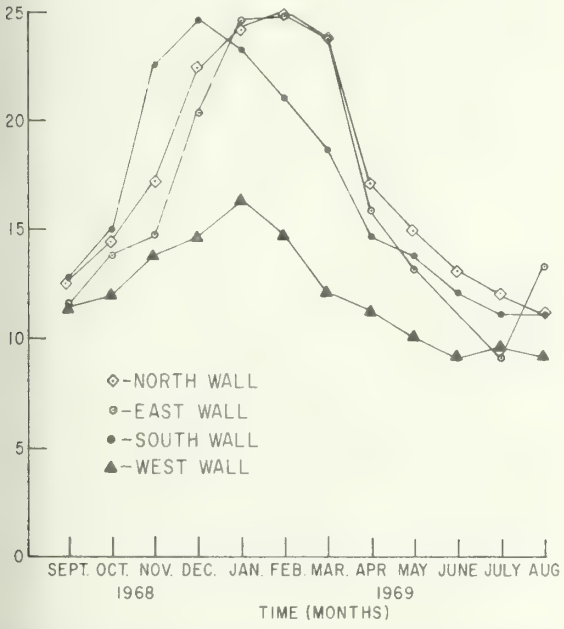


Figure 7. — Time plot of moisture conditions in the exterio sheathing of the north-, east-, south-, and west-facing stud panels with no vapor barriers. (The areas defined by th line projected at 20 percent moisture content and by th four moisture-time plots indicate the duration and exter of excessive moisture conditions in the study panels.)

A better comparison of the effect of directio of exposure can be made on the basis of the area under the four moisture-time plots in figure 7 If a base line is established at the level of 20 per cent moisture content (wood decay activity cease below this level), then the areas defined by th base line and the various moisture-time plots rep resent a measure of the duration and extent o excessive moisture conditions recorded in th study panels. The areas defined can be expresse in terms of "moisture content-months." Com parison of these areas in figure 7 shows that th highest values (22 moisture content-months were associated with the east-facing panel followed by the north-facing panel with 1(the south-facing panel with 6, and the west facing panel with only 2. These comparisons in dicate a substantial difference among the fou directions of exposure.

Figure 8 shows the moisture-time plots for th wood siding of the same panels plotted in figur 7. Except for the west-facing panel which peake at 16 percent, the moisture peaks for the sidin exposed in various directions were almost identi cal (24 to 25 percent). The moisture content o

e siding for the west exposure peaked rapidly January and then decreased to a low of 9 per-nt with the approach of summer. Solar radi-ion and the subsequent heating of the surface of e siding were probably responsible for the rapid ecrease and the low moisture content of the siding the west-facing panel during the summer.



igure 8. — Time plot of moisture conditions in the wood sid-ing of the north-, east-, south-, and west-facing study pan-els with no vapor barriers.

The mechanism responsible for the differences esulting from direction of exposure can be related o the environmental factors of wind and solar adiation. The amount of wind or air moving cross the exterior surface of a wall panel has direct effect on the amount of moisture moving hrough the panel to the outside environment. A rapid rate of moisture movement through the vall with no vapor barrier results in less accumu-ated moisture in the siding and sheathing. Thus, he siding and sheathing of the wall panels receiv-ng the prevailing winds during the winter would ogically have lower peaks and shorter periods of igh moisture content than those panels not sub-ect to the wind's drying effect. Similarly, the nterior components of panels receiving the heat-ng effects of the sun would tend to have lower noisture contents.

Figure 8 shows that the moisture peak of the iding of the west-facing panel was substantially lower (16 percent) than the peaks of the corresponding panels facing the other three cardinal directions. According to the Athens bureau of the National Weather Service (located 5 miles from the test house), the prevailing wind direction for the winter period (November through May) was westerly. Hence, the wind is believed to be mainly responsible for preventing the occurrence of high moisture conditions in the west-facing panel.

Solar radiation was also probably responsible for some of this variation. Even in winter the wall surfaces receiving the highest radiation are at a higher temperature than those not facing the sun, especially during the afternoon when the air temperature is higher. The slightly higher temperatures of the siding exposed to higher solar radiation would cause accelerated drying of the exterior of the panel; hence, the peak moisture content of the siding would tend to be lower.

Both wind and solar radiation probably augmented each other in lowering the moisture conditions in the west-facing panel without a vapor barrier. The east, south, and west exposures received considerable solar radiation during the daylight hours, and the west exposure received the major effect of the wind during the winter. It follows, therefore, that the panel that received the maximum effects of both solar radiation and wind would be substantially lower in accumulated moisture than the corresponding panels in the other walls.

Figure 8 also indicates that moisture content of the siding will be lowered when the solar radiation acts without the effect of wind. In the south-facing panel, moisture content of the siding rose quickly during early winter but dropped rapidly when spring approached and more solar radiation became available for drying the wall.

Moisture peaks were almost identical (24 to 25 percent) in the siding of the north- and east-facing study panels without vapor barriers (fig. 8). These two panels received little direct effect of the prevailing wind. Although the north panel received little solar radiation, the east panel received substantially more radiation during the morning until noon. However, the cool ambient air during the morning probably prevented the east panel from being heated to any degree.

Interior and exterior vapor barriers. — Direction of exposure had little effect on moisture contents recorded in the siding and sheathing of the panels with vapor barriers. This uniformity resulted because the barriers held the moisture conditions within a limited range (10 to 16 percent). There was also little variation (9 to 10 percent) in the moisture conditions recorded in the studs of these panels. Low moisture conditions were maintained in the wall cavities of these panels because of the vapor barriers. However, because the moisture sensors were located near the geometric centers of the studs, the data recorded were not entirely representative of any rapid changes in moisture conditions which might have occurred in the outer portions of the studs.

CONCLUSIONS

The low moisture conditions observed in the study panels with interior and exterior vapor barriers would indicate that the position of the barrier does not significantly affect the moisture content of the sheathing in a heated and air-conditioned wood-frame structure. It should be noted, however, that this conclusion is applicable only to insulated walls exposed to climates similar to that of Athens, Georgia, where prolonged hot and humid summers and cold winters are rarely encountered.

The position of the vapor barrier in an insulated wood-frame wall exposed to long, cold winters in northern climates would be critical. In these climates, positioning the barrier outside the insulation would result in extensive moisture condensation in wall cavities. Conversely, in the hot and humid gulf coast, the placement of a vapor barrier inside the insulation would certainly run the risk of severe moisture condensation during summer if the interior of the wall were exposed to air conditioning.

The high moisture levels observed in the siding and sheathing of the insulated walls without vapor barriers are considered hazardous and undesirable. Although the moisture contents of both the sheathing and the siding remained high for prolonged periods, especially in winter and spring, the hazard of decay was low at that time because of the low wall temperatures. The hazard that does exist involves the effect of the moisture on the durability of the exterior paint. Excessive moisture transmission has been known to be partially responsible for blistering and cracking of paint. However, no paint failure was observed during the term of this study, probably because such deterioration requires 2 to 3 years to develop. High moisture conditions in the sheathing and siding likewise decrease the insulating efficiency of the wall. Large changes in moisture content can also cause excessive dimensional changes in the walls, resulting in nail popping and failure of paint and joints.

Perhaps the most interesting observation made in the study was the effect of direction of exposure on the moisture levels in the sheathing and siding. When an insulated wall without a vapor barrier is subjected to the prevailing winds and the heating effects of the sun, lower amounts of accumulated moisture will be observed in exterior sheathing and siding than in those of identical walls not exposed to such drying effects.

The moisture contents of the studs located in the panels with vapor barriers remained almost constant (10 percent) during the study. However, the studs located in the panels without vapor barriers varied from about 10 to 13 percent. This variation, which was smaller than expected, was due to the mid-location of the moisture sensor, making it less responsive to rapid fluctuations in moisture conditions than if sensors had been near the wood surface.

The overall results of this study indicate that a vapor barrier is definitely required in insulated walls exposed to a mild type of winter, as is found in Athens, Georgia. Although the position of the barrier does not appear to be critical (low moisture conditions were maintained in the sheathing of the panels with exterior or interior barriers), the interior or conventional placement of the barrier seems to be the convenient and technically sound choice for this climate.

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In a temperature-controlled test house in Athens, Georgia, a maximum moisture content of 23 percent, recorded during the summer near the vapor barrier in a wall panel with a barrier inside the insulation, was of short duration and not considered hazardous. During the winter, a 25-percent maximum, recorded in the exterior sheathing of a panel without a vapor barrier, persisted for about 4 months and was considered hazardous. During this season, the wood components in the panels with vapor barriers inside or outside the insulation remained below 15 percent. Thus, in areas like Athens where walls are exposed to equal amounts of summer air conditioning and winter heating, the position of the vapor barrier apparently makes little difference in moisture conditions. Position of the barrier would be critical, however, in walls exposed to more extreme climates.

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JAN

SHORT FASTENERS

FOR CONTROL OF MAIL POPPING UNDER RESILIENT TILE FLOORING

by Charles O. Yoe

Short Fasteners for Control of Nail Popping Under Resilient Tile Flooring

by

Charles B. Vick, Wood Scientist
Forestry Sciences Laboratory
Athens, Georgia

INTRODUCTION

The satisfactory performance of thin, resilient tile on a wood-based floor system depends to a great degree on performance of the fasteners that hold underlayment, subflooring, and framing members together. These fasteners must be able to withstand stresses that are imposed on the floor system; otherwise, nail popping, cracks, and buckling will result. Nail popping is probably the most common defect to be found in such flooring. When nail heads protrude above the surface plane more than 0.005 inch, they are readily visible by reflected light over thin, smooth-surfaced tile flooring. Although these defects usually are not indicative of serious structural weakness, they are unsightly and costly to repair. Thus, the nuisance of nail popping tends to force homeowners, contractors, and architects to seek other finish flooring and base materials that will give more satisfactory service. Given this problem, the general intent of this study was to investigate means by which nail popping might be limited in plywood floor systems under resilient tile.

Previous Investigations

Investigators (1, 3, 4, 5) generally agree that nail popping is caused by one or a combination of factors, principal among these being

(1) shrinkage of wood away from the fastener head;

(2) cumulative outward creep of the fastener itself, resulting from stresses acting against the shank, point, and head of the fastener because of alternate swelling and shrinking of the wood; and

(3) failure in withdrawal resistance of the fastener.

Suddarth and Angleton (5) concluded that the amount of nail popping is directly and proportionately related to the amount of wood shrinkage but that nail length or depth of penetration exerted the greatest influence

on the amount of pop. They also stated (5, p. 6) that "The shrinkage occurring over the depth of penetration of an embedded nail is an upper bound to the maximum amount of pop to be expected in a given situation. ... The shrinkage occurring over one half of the depth of a board, which is completely penetrated by a nail, is an upper bound to the maximum amount of pop to be expected in a given situation."

There has been some dispute concerning Suddarth and Angleton's conclusion that repeated cycling of wood to high and low moisture contents causes cumulative outward creep of nails of high withdrawal resistances. Though this conclusion is acceptable to Stern (4) with respect to uncoated and cement-coated nails with smooth shanks, he is in sharp disagreement regarding properly grooved or threaded nails of high withdrawal resistances under similar conditions of exposure. Luxford (3) compared the amount of nail popping among several types of nails and demonstrated that annularly grooved and helically threaded nails had less additional shank exposure than nails with smooth shanks when boards containing these nails were dried. Though no causal factors were established for this effect, he suggested that grooved and threaded nails may be more satisfactory than nails with smooth shanks in resisting nail popping. It should be noted that the conclusions of all three investigations were based on the performance of nails that had their points completely embedded in the wood.

Study Objectives

These investigations pointed to several possibilities for limiting nail popping from wood-based floor systems under resilient tile flooring. First, the depth of nail penetration could be reduced significantly. In fact, the common practice of using long nails to fasten underlayment directly to floor joists through subflooring could be avoided altogether. Instead, shorter fasteners with high withdrawal resistances could be used to fasten underlayment only to subflooring. Such a practice might completely eliminate all nail popping associated with dimensional changes in floor joists. Second, as indicated by Suddarth and Angleton (5), some reduction of nail popping can be expected when a nail point completely passes through subflooring instead of partially penetrating it.

As pointed out by Stern (4) and Suddarth and Angleton (5), there is conflicting evidence that the amount of outward creep of a fastener in wood is directly related to its withdrawal resistance. However, this evidence is founded on data from nails that did not completely penetrate wooden members. The experimental portion of this report was therefore designed to resolve the question of whether withdrawal resistance of the fastener influences its resistance to outward creep, particularly when the point of the fastener completely passes through underlayment and subflooring.

Long vs. Short Nails in Floors

The following hypothetical illustration is included to show how nail popping and dimpling can develop in a plywood-based floor system, even when the floor is fastened with nails of high withdrawal resistance. This illustration shows in particular how nail length and placement in the floor can affect the amount of nail popping. It further shows that nail popping and dimpling cannot be completely eliminated with conventional nails when significant changes in moisture content take place in the wood.

The moisture contents and changes assumed in this illustration were based on experience from homes in the Southeast. These conditions are somewhat extreme, but they do exemplify the potential severity of nail popping in many floors. Dimensional changes corresponding with the assumed changes in moisture content of wood components were calculated from published values of average shrinkage of southern yellow pine (6). The total possible shrinkage in thickness of plywood was assumed to be 5 percent of its original dimension and that of the lumber joist to be 6 percent of its depth. For each 1-percent change in moisture content, the change in dimension of the wood component was assumed to be one-thirtieth of the total possible dimensional change.

Figure 1 represents a section of a plywood-based floor system constructed with 5/8-inch-thick plywood underlayment and $\frac{1}{2}$-inch-thick plywood subflooring over 2- by 8-inch lumber joists. A long annular-grooved nail, 2-3/8 inches in length, fastens underlayment to the floor joist through the subflooring. Between the joists, a shorter annular-grooved nail, $1\frac{1}{4}$ inches long, fastens underlayment to the subflooring without penetration of joists or blocking. Nails fastening subflooring to joists are not shown in figure 1 because they are not relevant to the problem of nail popping.

The lumber joist and plywood subflooring in figure 1A are assumed to have a moisture content of 16 percent. In the Southeast, such a moisture level is common in joists and subflooring at the time underlayment is installed in a house. Even though these materials are usually purchased in a reasonably dry condition, they regain considerable moisture during outdoor storage and construction. The moisture content of the underlayment is assumed to be 10 percent at the time of fastening to the subfloor system.

After installation, however, underlayment normally gains moisture through contact with damp subflooring and exposure to outdoor air. The moisture content of the underlayment is assumed to increase to 16 percent, as shown in figure 1B. This increase causes a corresponding expansion in thickness of 0.006 inch. Because this expansion must take place upwards from the subfloor, 0.006-inch dimples develop in the surface of the underlayment at the heads of both nails. Dimples formed by large, countersunk nail heads can be as visually objectionable in thin tile flooring as nail pops of equal magnitude. In some cases, however, nails may be withdrawn by the heads with repeated expansions, particularly nails with shallow penetration or low withdrawal resistance.

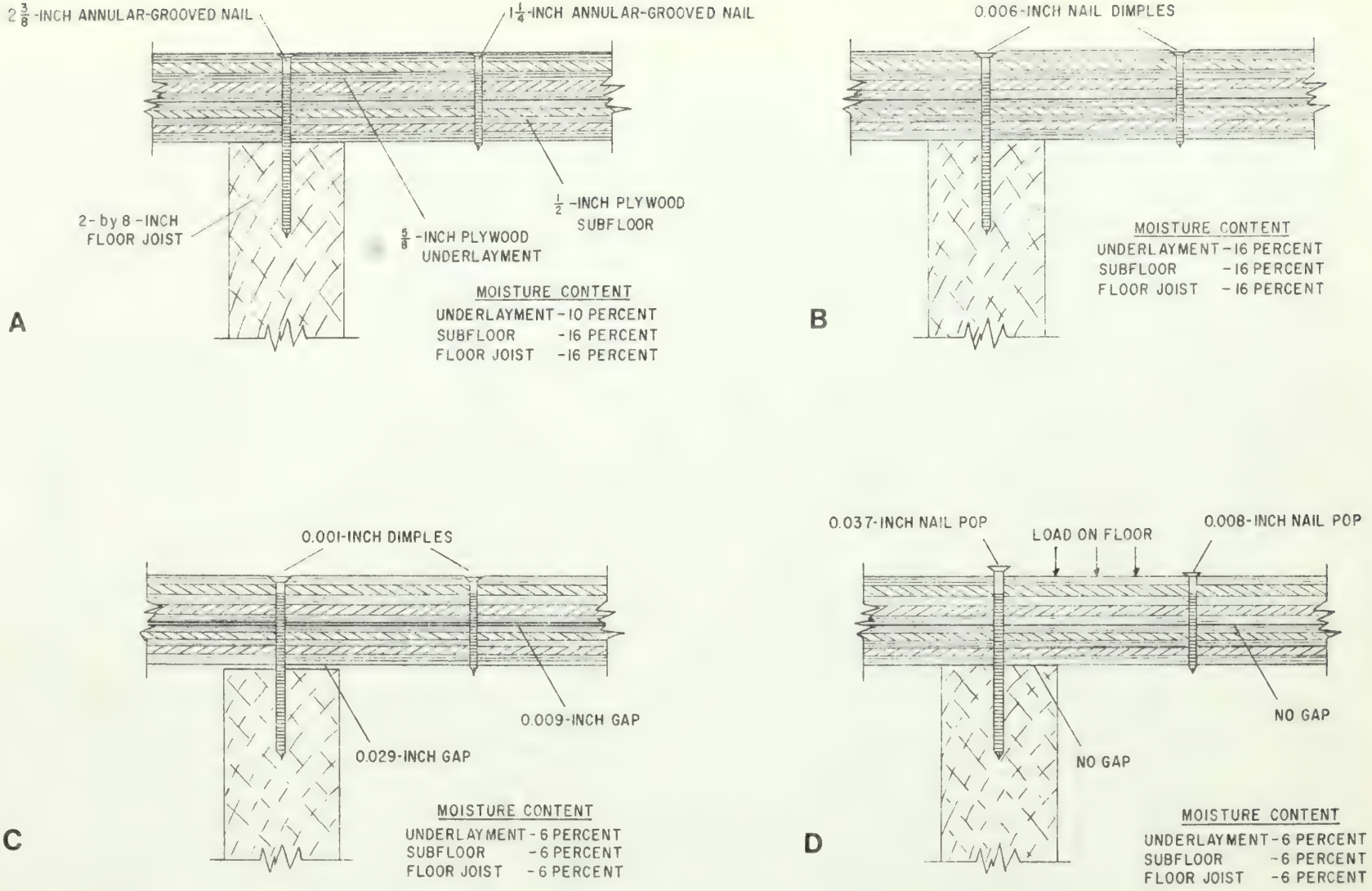

Figure 1.--Nail popping and dimpling in a plywood-based floor system. (A) Position of system at installation, (B) Position after system gains moisture through contact with subflooring and exposure to air, (C) Position after system is enclosed and dries because of heating, (D) Position after system is subjected to [illegible] from foot traffic.

Once a house is enclosed and heating begins, the wood components dry and tend to reach a lower equilibrium moisture content. Floors over dry crawl spaces and other heated areas often dry to 6 percent moisture content, particularly with forced-air heating. If all wood components dried from the condition shown in figure 1B to 6 percent moisture content, then shrinkage would produce the condition shown in figure 1C. Shrinkage of the lumber joist along the length of the nail shank, which was originally embedded $1\frac{1}{4}$ inches, causes the shank to be additionally exposed 0.025 inch above the edge of the joist. At the same time, the subfloor shrinks a total of 0.008 inch and the underlayment shrinks 0.010 inch. Because both nail shanks completely pass through both underlayment and subflooring, it is assumed that shrinkage takes place equally about the centerline of each component. Thus, shrinkage causes the upper and lower surfaces of each component to move toward the centerline by an amount equal to one-half the total shrinkage of the component. If the nails in figure 1C remain fixed, then shrinkage creates a gap of 0.029 inch between the joist and subfloor (sum of the shrinkage of adjacent edges of joist and subfloor), a gap of 0.009 inch develops between the subfloor and underlayment, and dimples of only 0.001 inch remain at the heads of both nails in the surface of the underlayment. Then, as shown in figure 1C, shrinkage causes the underlayment and subfloor to be suspended only by the holding ability of that portion of the nail shank in each layer of flooring.

If this floor is subjected to repeated loading, such as by foot traffic, and the loading exceeds the holding ability of the nails in the underlayment and subfloor, then the gaps will be forced to close, as shown in figure 1D. In such a case, the longer nail will show a pop of 0.037 inch above the surface of the underlayment. The shorter nail, on the other hand, will show a pop of only 0.008 inch. If, however, the lower shank of the shorter nail had slipped through the subfloor instead of slipping in the underlayment, then there would be no nail pop at the head of the shorter nail. Thus, it should be apparent from this illustration that a short nail that did not penetrate any solid member after passing through the subfloor would be a distinct advantage in minimizing nail popping. The least reduction in nail popping would be 0.029 inch, or the distance of the gap between joist and subfloor (fig. 1C).

EXPERIMENTAL PROCEDURES

General

An experiment was conducted consisting of two tests. In the first, five types of short fasteners, each known to differ in withdrawal resistance, were tested for actual withdrawal resistances. This test was made in separate pieces of plywood underlayment and subflooring immediately after driving the fasteners and again 26 weeks later after the specimens had been subjected to $4\frac{1}{2}$ cycles of severe changes in moisture content. The initial test of withdrawal resistance was made in plywood at 17.5 percent moisture content--the point of maximum expansion for the plywood used in this test; after completion of $4\frac{1}{2}$ exposure cycles, the final test

was made at 6.5 percent moisture content. Such a change in moisture content between the time of driving the fasteners and testing them tends to cause a major loss in holding ability, particularly by smooth-shanked nails.

In the second test, the points of the same types of fasteners were driven completely through assemblies of plywood underlayment and subflooring and subjected to the same cyclic changes in moisture content as in the first test. Again, these fasteners were driven into plywood which had been preconditioned to 17.5 percent moisture content, the point of maximum expansion for the plywood used. Thus, during subsequent expansions of the wood in moisture cycling, there would be no upward pressure against the heads of the fasteners to cause partial withdrawal prior to measuring. At the end of each change in moisture content of the assemblies, the positions of the heads of the fasteners were measured for pop and creep with respect to the upper surface of the underlayment. Popping was considered to be any projection of the head of a fastener above the surface of the underlayment. Creep was considered to be cumulative outward or inward movement of a popped or projecting head of a fastener as the number of moisture cycles increased.

Materials

The five types of short fasteners selected for these tests are shown in figure 2. A detailed description of their characteristics is given in table 1.

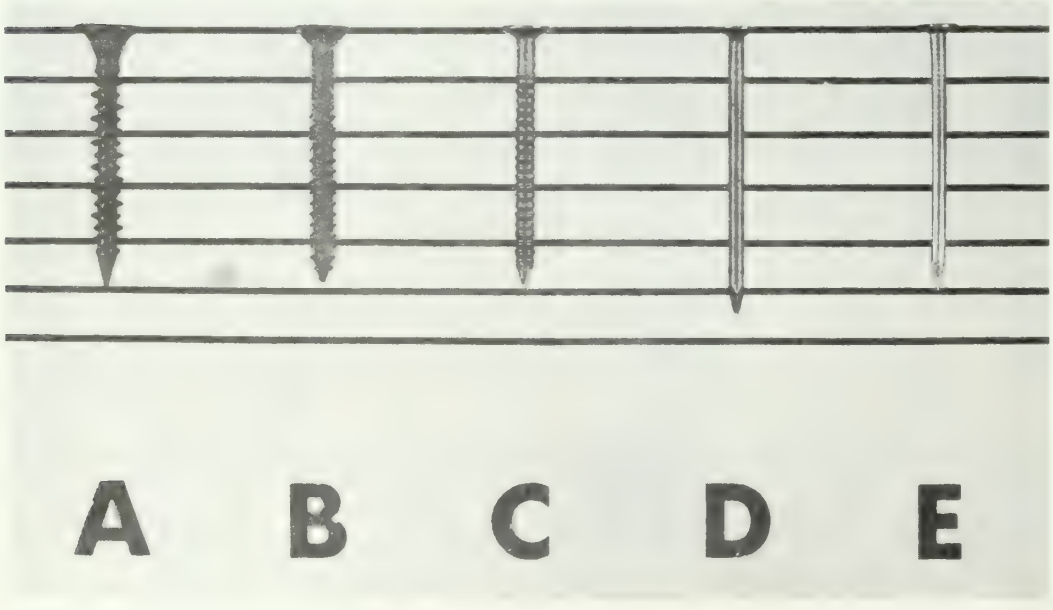

Figure 2.--Screws and nails used in tests. (A) Drywall screw, (B) Improved wood screw, (C) Annular-grooved nail, (D) Cement-coated wire nail, (E) Common wire nail.

Table 1.--Descriptions of screws and nails used in tests

Fastener type	Length	Root diameter	Major diameter	Head type	Head diameter	Point type	Finish	Remarks
		Inches			Inches			
Drywall screw	1¼	0.100	0.165	Bugle, Phillips	0.335	Diamond	Phosphate	Double-lead, power driven, no pilot hole
Improved wood screw	1¼	.100	.135	Flat, Phillips	.270	Concentric	Waxed	Double-lead, power driven, no pilot hole
Annular-grooved nail	1¼	.098	.107	Sinker	.250	Diamond	None	Underlayment nail
Cement-coated wire nail	1-3/8	.080	.080	Sinker	.185	Diamond	Cement	--
Common wire nail	1¼	.080	.080	Sinker	.205	Diamond	None	--

Grades and thicknesses of plywood for underlayment and subflooring were selected on the basis of what is typical for residential construction in the Southeast. When resilient tile and strip flooring are to be adjacently installed, it is common practice to use ½-inch-thick subflooring throughout the house and to build up the tile floor with 5/8-inch-thick underlayment to the finished level of the strip flooring. For these tests, the plywood for the underlayment and subflooring was southern pine with exterior glue lines. The subfloor material was cut from unsanded structural panels of 5-ply, ½-inch-thick, grade C-D plywood. The underlayment material was cut from 5-ply, 5/8-inch-thick, C-C plugged, Underlayment-grade plywood.

Withdrawal Resistance: Test I

Two types of specimens were used in withdrawal tests: one was a 6- by 7-inch piece of underlayment plywood; the other was an identically sized piece of subfloor plywood. Each specimen had six fasteners. Those fasteners in the specimens of underlayment were driven so that the heads were flush with the upper surface of the plywood, just as would be typical in floor underlayment. In the specimens of subflooring, the points of the fasteners penetrated the pieces but the heads remained 5/8 inch above the surface to correspond with normal placement of fasteners when 5/8-inch-thick underlayment is used above the subfloor. In each specimen, three of the fasteners were for testing withdrawal resistance before exposure to cyclic changes in moisture content and the remaining three fasteners were for testing withdrawal resistance after cyclic exposure. Ten specimens were used for testing each of the five types of fasteners in both underlayment and subfloor. Thus, withdrawal resistances for any one type of fastener in underlayment or subfloor, before or after cyclic exposure, were averaged from 30 observations.

Specimens were prepared by preconditioning 7- by 7-inch pieces of underlayment and subflooring to equilibrium for 4 weeks at 90 ± 3° F. and 90 ± 5 percent relative humidity. A 1- by 7-inch strip was then cut from the edge of each piece. These strips were ovendried, and their moisture contents were determined. Six fasteners of a single type were driven into the remaining 6- by 7-inch pieces of plywood. The nails were driven by hammer and the screws by screwdriver.

Three fasteners from each specimen were tested immediately at a moisture content of 17.5 percent. The remaining fasteners were then subjected to $4\frac{1}{2}$ moisture cycles. Each cycle consisted of a 2-week exposure at 90 ± 3° F. and 30 ± 5 percent relative humidity, followed by a 4-week exposure at 90 ± 3° F. and 90 ± 5 percent relative humidity. The moisture content of the plywood was approximately 6.5 percent at low humidity and 17.5 percent at high humidity. At the end of $4\frac{1}{2}$ cycles, i.e., at 6.5 percent moisture content, the remaining three fasteners in each specimen were tested.

Loads for axial withdrawal of fasteners were applied and measured with a universal testing machine. The fasteners were loaded at a constant rate of 0.10 inch per minute until maximum loading was reached. Those fasteners driven into subfloor specimens were withdrawn in a tension loading system (2). A different loading system was used to withdraw the fasteners in underlayment because the heads of the fasteners were embedded in the face of the specimens. A compression test was devised so that the load acted on the point of the fastener to determine axial withdrawal resistance.

Creep Resistance: Test II

A test specimen consisted of strips of plywood underlayment and subflooring, each 3 inches wide and 42 inches long, with test fasteners holding the two strips together. Twenty fasteners, four of each of the five types, were randomly located at 2-inch intervals along the middle of each specimen. There were 16 specimens altogether, allowing 64 observations for each type of fastener.

The strips for specimens were randomly selected and cut from four 4- by 8-foot sheets of plywood underlayment and four sheets of subflooring. These strips were cut 1 inch wider than the finished specimen strips. The additional 1 inch of width was used to determine moisture content after ovendrying. These materials were preconditioned to an average moisture content of 17.5 percent at 90 ± 3° F. and 90 ± 5 percent relative humidity.

Test nails and screws were driven by hand so that the heads of the fasteners projected 0.005 to 0.010 inch above the surface of the underlayment. This projection prevented the heads from countersinking during subsequent cycles of high humidity, which would have made it difficult to measure the positions of the head. After the initial positions of the heads were measured, the specimens were subjected

to the same $4\frac{1}{2}$ cycles of high and low relative humidity as in Test I. Measurements of head positions were made throughout the exposure period after completion of each phase of the cycles. These measurements were all reported as changes from the initial position. A specially constructed dial micrometer, graduated to 0.001 inch, was used to measure position of the heads above the surface of the underlayment.

RESULTS AND DISCUSSION

Axial withdrawal resistances of the five types of fasteners are shown in figure 3 for underlayment and figure 4 for subflooring. These are averages based on 30 observations taken before and after cyclic changes in moisture content of both underlayment and subflooring. The results of popping and cumulative creep of these fasteners during similar cyclic changes in moisture content are summarized in figure 5; each data point on the latter graphs is the average of 64 observations.

Of all the fasteners, the drywall screws had the greatest withdrawal resistance in both underlayment and subflooring. In underlayment, these screws actually increased in withdrawal load from an average of 343 pounds to 413 pounds after $4\frac{1}{2}$ cyclic changes in moisture content (fig. 3). The same effect occurred in subflooring, where withdrawal load increased to 296 pounds from an initial average of 233 pounds (fig. 4). There was a greater withdrawal resistance in the underlayment than in the subflooring because of the greater thickness of the former.

As figure 5 shows, the drywall screws did not exhibit cumulative outward creep as the specimens underwent repeated cyclic changes in moisture content. The heads of the screws did pop as much as 0.010 inch above the upper surface of the underlayment during the dry portions of the cycles. Of course, such popping is to be expected with any mechanical fastener in wood, simply because the wood shrinks during drying and exposes the head.

The improved wood screws developed withdrawal resistance in subflooring comparable to that of the drywall screws. Initial withdrawal load in subflooring averaged 224 pounds; after cyclic changes in moisture content, average load increased to 294 pounds (fig. 4). However, withdrawal resistance of these screws in underlayment was less than one-half that of the drywall screws either before or after cyclic changes in moisture content. Initial load in underlayment averaged 157 pounds; after cycling, the load averaged only 144 pounds (fig. 3). The reason for the lower withdrawal resistance in the thicker underlayment is apparent after examining the configuration of the screw in figure 2. The upper portion of the screw shank, which is normally embedded in 5/8-inch-thick underlayment, is without screw threads for approximately 3/8 inch of its upper length. Thus, 60 percent of the embedded upper shank offered the withdrawal resistance of a smooth-shanked fastener.

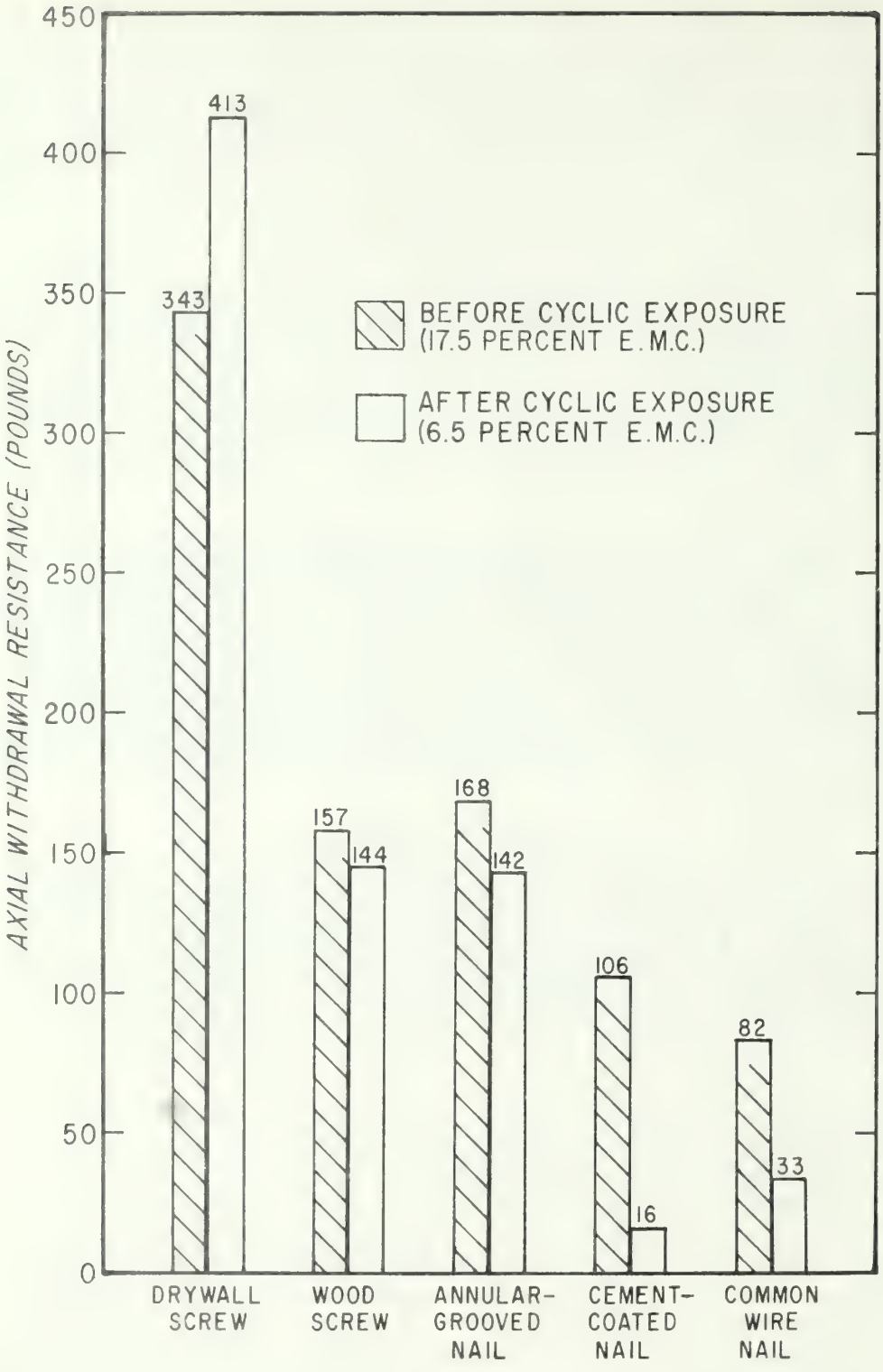

Figure 3.--Average axial withdrawal resistances of five types of fasteners in 5/8-inch-thick plywood underlayment before and after cyclic changes in moisture content.

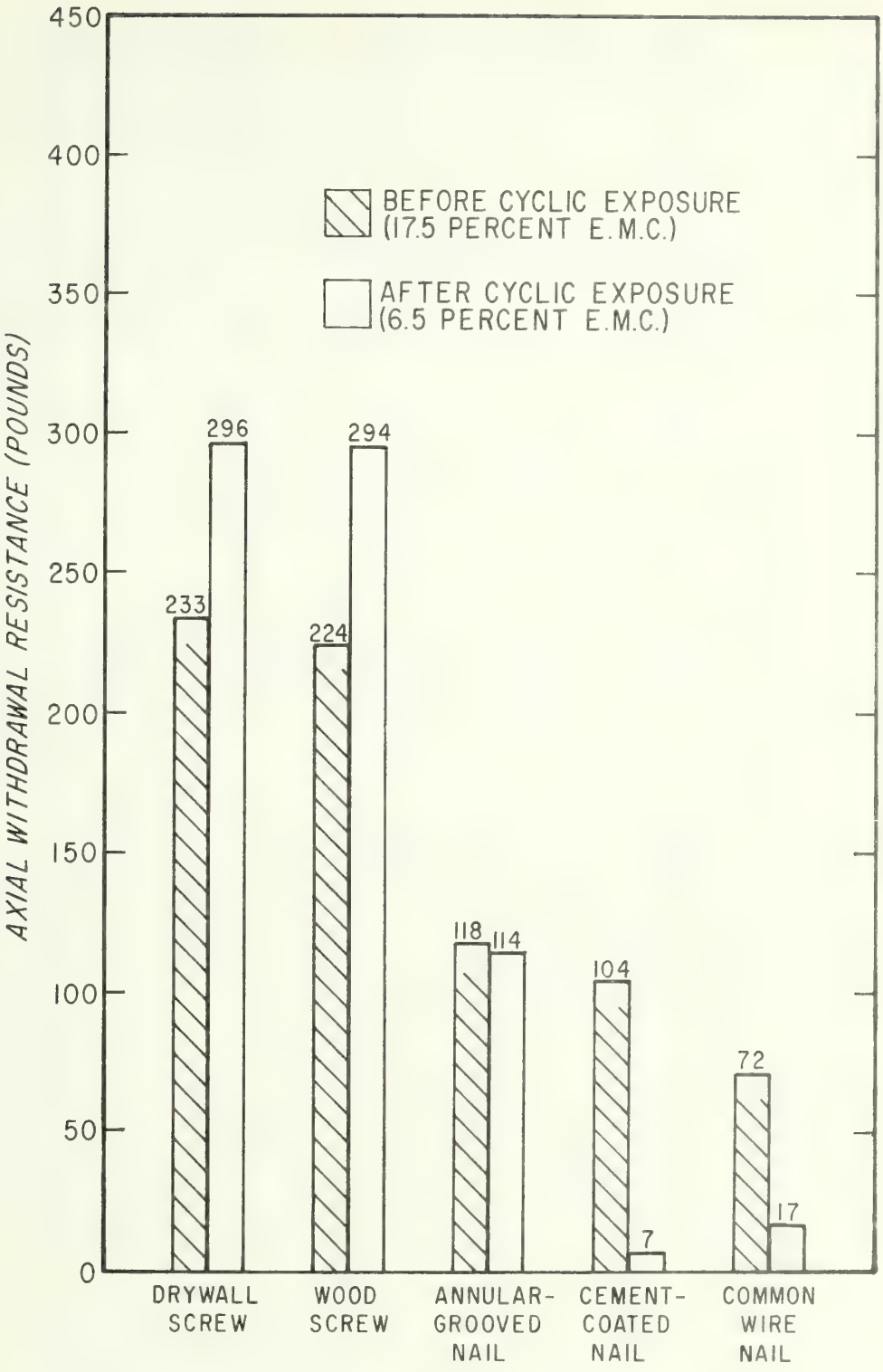

Figure 4. --Average axial withdrawal resistances of five types of fasteners in $\frac{1}{2}$-inch-thick plywood subflooring before and after cyclic changes in moisture content.

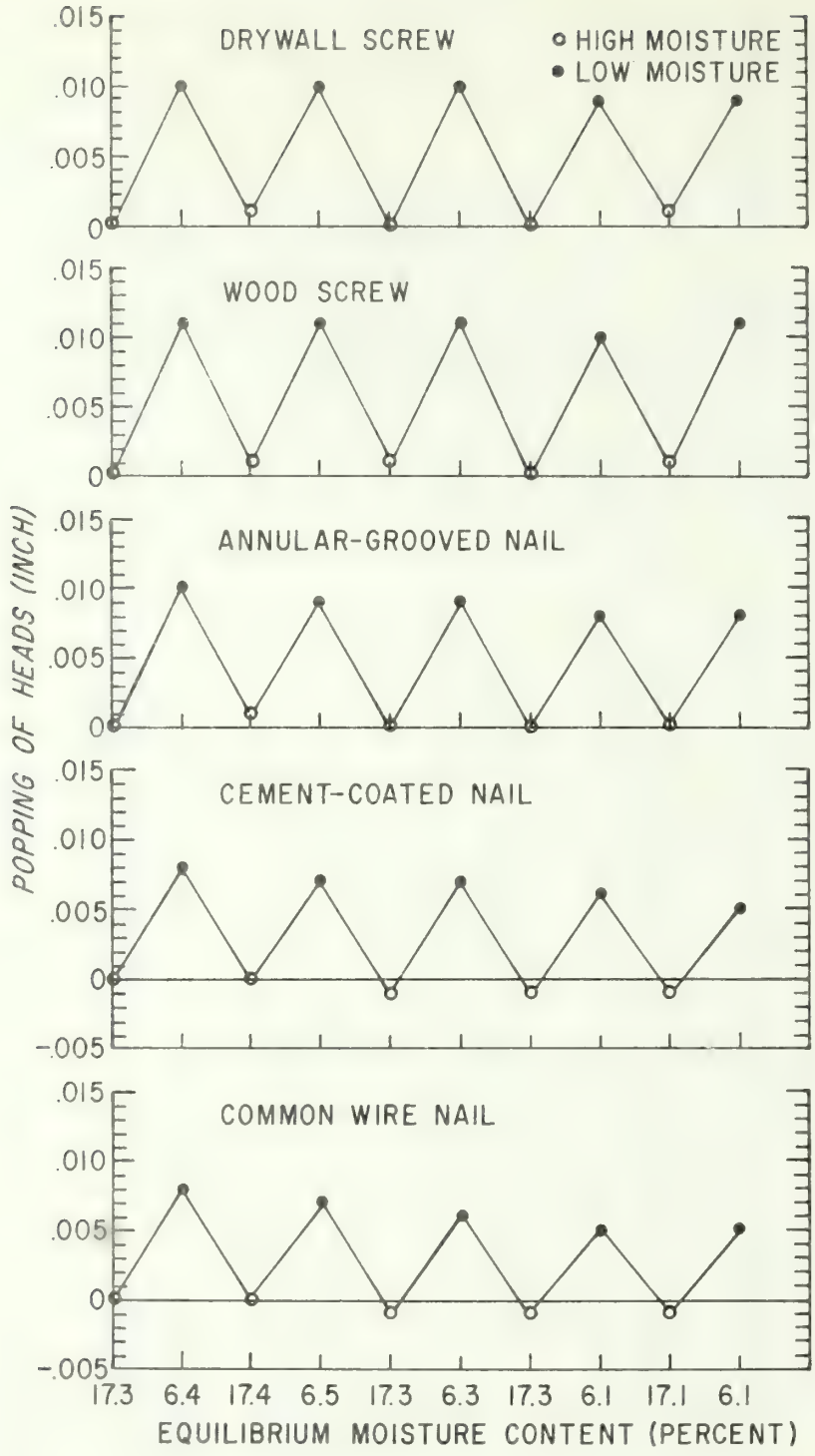

Figure 5.--Average popping and cumulative creep of the heads of five types of fasteners in assemblies of plywood underlayment and subflooring during cyclic changes in moisture content. In each graph, zero indicates the initial position of the heads, which projected 0.005 to 0.010 inch above the surface of the underlayment. Peaks indicate low moisture; valleys indicate high moisture.

The improved wood screws exhibited no tendency to cumulative outward creep after repeated cycling, as shown in figure 5. During the dry portion of the cycles, maximum pop of the head was 0.011 inch and remained fairly constant throughout the test. Again, this popping was caused solely by shrinkage of the plywood.

The annular-grooved nail had greater withdrawal resistance in underlayment and subfloor plywood than did that of any of the other nails. The initial withdrawal load in underlayment averaged 168 pounds; after cyclic exposure, the average load dropped to 142 pounds (fig. 3). There was an insignificant loss in withdrawal resistance in subflooring after exposure. Initial load in subflooring averaged 118 pounds; after cyclic exposure, the average load was 114 pounds (fig. 4).

Cyclic changes in moisture content caused no cumulative outward creep of the annular-grooved nails. However, there was some inward creep; cumulatively, this amounted to 0.002 inch over the $4\frac{1}{2}$ exposure cycles (fig. 5). Maximum pop during the dry portions of the cycles was 0.010 inch.

The cement-coated nail had only temporary withdrawal resistance. Initial withdrawal load in underlayment averaged 106 pounds; after cyclic changes in moisture, the nail had an average load of only 16 pounds (fig. 3). This severe loss in withdrawal resistance also occurred in the subflooring, where withdrawal load dropped from 104 pounds to only 7 pounds (fig. 4).

The common wire nail, equal in size to the cement-coated nail, was lower in average initial withdrawal resistance than was the cement-coated nail. This load was 82 pounds in underlayment (fig. 3) and 72 pounds in subflooring (fig. 4). After cyclic changes in moisture content, the common nail also had a major loss in withdrawal resistance, with a drop to 33 pounds in underlayment and 17 pounds in subflooring.

As with the other fasteners in this study, neither the cement-coated nor the common nails were subject to cumulative outward creep during cyclic exposure (fig. 5). However, both nails underwent 0.003 inch of inward creep during the wet portions of the cycles. They also underwent less total popping than the screws or annular-grooved nail during the dry portions of each cycle. Average pop for the two nails was 0.008 inch after the initial drying period; at the end of the exposure test, total pop averaged 0.005 inch.

None of the five types of fasteners underwent cumulative outward creep as a result of alternate shrinking and swelling of the flooring materials. Thus, from this series of tests, no relationship could be established between cumulative outward creep and the withdrawal resistance of a fastener. The fastening technique probably accounted for the lack of cumulative outward creep, i.e., because the points of these short fasteners passed completely through the subflooring, they were not ob-

structed in any way as they emerged from the subflooring. Thus, there were no bearing surfaces for the points of the fasteners to act against as the flooring materials underwent dimensional changes.

There appeared to be some relationship between higher cumulative inward creep and low withdrawal resistance. The cement-coated and common wire nails underwent the greatest amount of inward creep--0.003 inch. At the same time, these nails had severe losses in withdrawal resistance. The annular-grooved nail also underwent inward creep amounting to 0.002 inch. However, in this case, the inverse relationship between inward creep and withdrawal resistance was not very strong: the annular-grooved nail showed little loss in withdrawal resistance during cyclic exposure, and initial withdrawal resistance of this nail in underlayment slightly exceeded that of the wood screw.

There is no substantiated explanation as to why the cement-coated, common wire, and annular-grooved nails underwent cumulative inward creep or why there was less total popping initially by the smooth-shanked nails than by the other fasteners. It can only be speculated that the underlayment was not restrained and slipped upwards along the shanks of the nails. This slipping could occur if the nails had relatively low pull-through resistances as the underlayment underwent dimensional changes, particularly in the case of the two smooth-shanked nails.

As cumulative outward or inward creep did not prove to be a problem with these short fasteners, one of the most important considerations remaining is that underlayment and subflooring be securely fastened together. There were indications from these tests that the smooth-shanked nails will not provide adequate holding ability in plywood floors. Several problems could develop when moisture changes take place in floors nailed together with fasteners of such low holding ability. The edges of the underlayment could loosen and move vertically so that cracks eventually develop in the tile at the joints between pieces of plywood. Or, in the case of extreme dimensional changes, the underlayment could buckle. Furthermore, squeaks are quite common when nails holding layers of flooring together are loosened. In general, experience has shown that screws and nails of high and long-term holding ability can give more assurance of trouble-free service.

It should be noted that popping can occur even when nails have high withdrawal resistance and their points pass completely through the subflooring. Such popping depends entirely on the amount of wood shrinkage that takes place. Even though maximum popping in figure 5 was only 0.011 inch over an extreme change in moisture content (from approximately 17 to 6 percent), any popping in excess of 0.005 inch can be objectionable under thin, resilient tile. When there is a possibility that shrinkage will occur after fastening, the heads of the fasteners can be countersunk approximately 0.015 inch to compensate for the expected shrinkage. However, such a practice can cause dimpling in the surface of thin, resilient tile if heads are as large as $\frac{1}{4}$ inch in diameter. The large bugle head of the drywall screw would certainly cause a dimple,

and heads the size of the wood screw and annular-grooved nail ($\frac{1}{4}$ inch in diameter) have also been known to cause dimples. Thus, a reduction in diameter of the heads to 5/32 inch or less by fastener manufacturers could reduce the problem of dimpling.

CONCLUSIONS

Short fasteners can be used to reduce nail popping significantly in plywood floor systems. Short screws or nails should be used to fasten underlayment only to subflooring, rather than long nails being used to fasten underlayment to floor joists through subflooring. This fastening technique eliminates all nail popping heretofore caused by extreme moisture content and dimensional changes in the floor joists.

The short screws and nails used in this study were not subjected to cumulative outward creep during cyclic changes in moisture content of the plywood flooring when the points of these fasteners passed completely through the subflooring. Fasteners of low and temporary withdrawal resistance were no more subject to cumulative outward creep than were fasteners of high and long-term withdrawal resistance. Therefore, no relationship could be established between the withdrawal resistance of a fastener and cumulative outward creep.

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Visitors' Preferences for Certain Physical Characteristics of Developed Campsites

by

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Visitors' Preferences for Certain Physical Characteristics of Developed Campsites

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Recreation managers and planners have at their disposal a considerable fund of information concerning the suitability of specific tracts of land for development, the appropriate mix of facilities and activities, the cost of resource development, and required safety and maintenance standards. This information is a vital part of recreational planning. It might aptly be called the "macroaspect" of such planning and development.

Little is known, however, about the "microaspect" of site development. For example, once the decision has been made to develop a recreational site such as a campground or picnic ground, what criteria does one use to decide how it should be developed? What factors within the site itself need to be considered to maximize the recreational experience of visitors and to provide an optimal level and quality of service? We know little about the factors that stimulate users to choose one site, or one part of the site, or one campsite within a complex, over another.

We frequently observe that certain family units within a developed site, whatever its kind, are used much more heavily than others. Why? Certainly, this use indicates that the chosen units are preferred and thus likely provide greater total benefit and satisfaction to users. Within a developed site, units having the characteristics that make them more desirable, and thus more in demand, receive a disproportionate share of use. This use leads to a faster rate of decline, from the standpoint of soils and vegetation, than that which occurs on less heavily used units.

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If user preferences were better known, developed sites and individual units within them might be designed to provide much more satisfaction to users and at the same time prevent concentrated use by better distributing the use load.

This report describes a study to determine which characteristics of developed campsites are important to users.[2] A developed campsite is defined as a single family unit, generally consisting of a parking spur, picnic table, tent pad, fireplace, and garbage disposal unit, within a campground. To enhance the credibility of the results, three data sources were used to determine visitor preferences: personal interviews, self-administered questionnaires, and observations concerning actual occupancy of the campsite. This was a cooperative study by personnel of the Southeastern Forest Experiment Station and the National Forest System.

Information was obtained during summer camping seasons from 1966 through 1970 at the Indian Boundary Campground, Tellico Ranger District, Cherokee National Forest. The campground is located at a 2,000-foot elevation in the Appalachian Mountains, 18 miles from Tellico Plains, Tennessee, in a well-stocked pine-hardwood stand. The site contains a 96-acre lake and provides camping, picnicking, fishing, swimming, boating, and a host of other recreational activities. A campfire theater seating 700 has been built in which educational programs are conducted several evenings each week throughout the recreational season.

In 1966, 58 campsites were opened to public use. Additional campsites were opened in 1967 and in 1969. Staggered opening dates were necessary to another study designed to test the effect of timing of overstory reduction on development of ground cover. This report is based on an analysis of only 21 of the campsites opened in 1966, because of the longer period of observations available.

In 1966, the first year that the campground was open, about 10,000 visitor-days[3] of use was estimated between May 28 and September 6 (Labor Day). By 1970, use had tripled to just over 31,000 visitor-days. Only part of this increase, 11.7 percent, occurred on two campground sections which had been opened in 1967 and 1969. Most of the increase in use occurred on the original campsites opened in 1966 and on which this analysis is based.

An appreciable variety of campsites is available at Indian Boundary Campground. The only major components of the campsites that might be considered homogeneous are the facilities themselves. Tables with con-

[2]Esthetics and landscape composition were not included in determining the characteristics of individual campsites. The authors recognize that these variables probably played an important part in campsite selections and in visitor responses to the questions. The subjective and undefinable nature of these variables, however, would have made it extremely difficult, if not impossible, to quantify the role that esthetics and landscape composition played in camper preferences.

[3]The presence of one or more persons for continuous, intermittent, or simultaneous periods aggregating 12 hours. A visitor-day may be comprised of use by one person for 12 hours, 12 persons for 1 hour, or any equivalent combination of individual or group use, either continuous or intermittent.

crete tops and wooden benches are standard; fireplaces consist of a circular, 4-foot-diameter concrete base with a metal grill; tent pads are 12 by 14 feet with a gravel base; and garbage units are sunk in the ground and are operated by a foot-pedal lid at ground level. Parking spurs are approximately 50 feet long and oriented to the campground road such that camping trailers can be backed in easily.

METHODS

Three research studies were installed on Indian Boundary Campground in early 1964. The studies, although concerned with different aspects of the problem of campsite development, were closely related. One of these studies, the basis for this report, was conducted to determine camper preference for physical characteristics of the family campsite. The other studies were designed to investigate biological and ecological relationships and included the following objectives: (1) To determine the response of understory vegetation to variations in timing and intensity of reduction of overstory density (number of trees removed),[4] and (2) to determine which native and introduced species of understory vegetation are best suited for planting on developed recreational sites.[5] These studies provided the major data inputs concerning the vegetative characteristics of individual campsites as presented in this report.

Campsite Characteristics

Three principal classes of data were obtained to describe the physical characteristics of campsites: (1) Location relative to other campsites and general facilities in the campground, (2) arrangement of facilities (e.g., table and fireplace) within the family campsite, and (3) the amount and character of campsite vegetation. These data were obtained only on the 21 study campsites opened in 1966.

Location of Campsites

Straight-line distances, in feet, between each campsite and all facilities were measured from an aerial photograph of the campground. Distances were measured from the center of the campsite, defined as the approximate center of the triangle formed by the table, fireplace, and tent pad.

The average distances from the centers of the various study campsites to the major campground facilities, and coefficients of variation (CV) of the mean for each variable, are shown on the next page:

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[4] James, George A., and Cottrell, Richard L. To cut or not to cut. J. For. 66: 57-59. 1968.

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Facility	Straight-line distance (feet)	Coefficient of variation[6] (percent)
Nearest comfort station	192.2	38.6
Nearest water hydrant	107.1	55.4
Nearest shoreline	590.6	30.8
Nearest fishing pier (earthen)	1,109.5	29.7
Developed swimming beach	725.9	30.0
Outdoor theater	586.0	41.1
Grassed playfield (open)	538.4	32.8
Nearest campsite	85.4	20.6
Nearest three campsites (average)	106.8	12.0

Arrangement of Campsite Facilities

Placement and arrangement of campsite facilities were determined as follows:

(1) Distance, in feet, from the end of the parking spur to the table, fireplace, and tent pad.

(2) Location of table, fireplace, and tent pad relative to the orientation of the parking spur, as determined by the angle between each facility and a straight line projected through the long axis of the parking spur.

(3) Amount of area in square feet between the table, fireplace, and tent pad.

(4) Relative position of the table, tent pad, and fireplace, indicating how close to a straight-line arrangement they lie, as opposed to being uniformly distributed about a central point.

[6]The CV measures the average deviation of observations from the mean expressed as a percentage of the mean and indicates the range of choice available to campers with respect to campsite location. The larger the CV, the greater is the range of choice (in distance) between campsite and specific facility. For example, the CV of 38.6 percent for comfort stations indicates that campers had a choice of campsites 38.6 percent closer or farther than the average distance to a comfort station. With campsites averaging 192 feet from a comfort station, a CV of ±38.6 percent indicates a range from 118 to 266 feet.

The arrangement of facilities within campsites followed a triangular pattern, but placement was extremely variable with respect to their location relative to the parking spur, although much less so with respect to their location relative to one another. CV's for mean distances between facilities are shown in figure 1. CV's for mean distances between facilities were comparatively smaller than the CV's for mean distances between facility locations and parking spur. Locations of tables and tent pads, especially, were extremely variable, with CV's of 38.8 and 40.4 percent for mean distances from the spur. The average placement of the facility grouping relative to the long axis of the spur was 176°, with a CV of 29.1 percent. The mean area within the facility grouping, the triangular area formed by the picnic table, fireplace, and tent pad, was 850 square feet, with a CV of 20.5 percent.

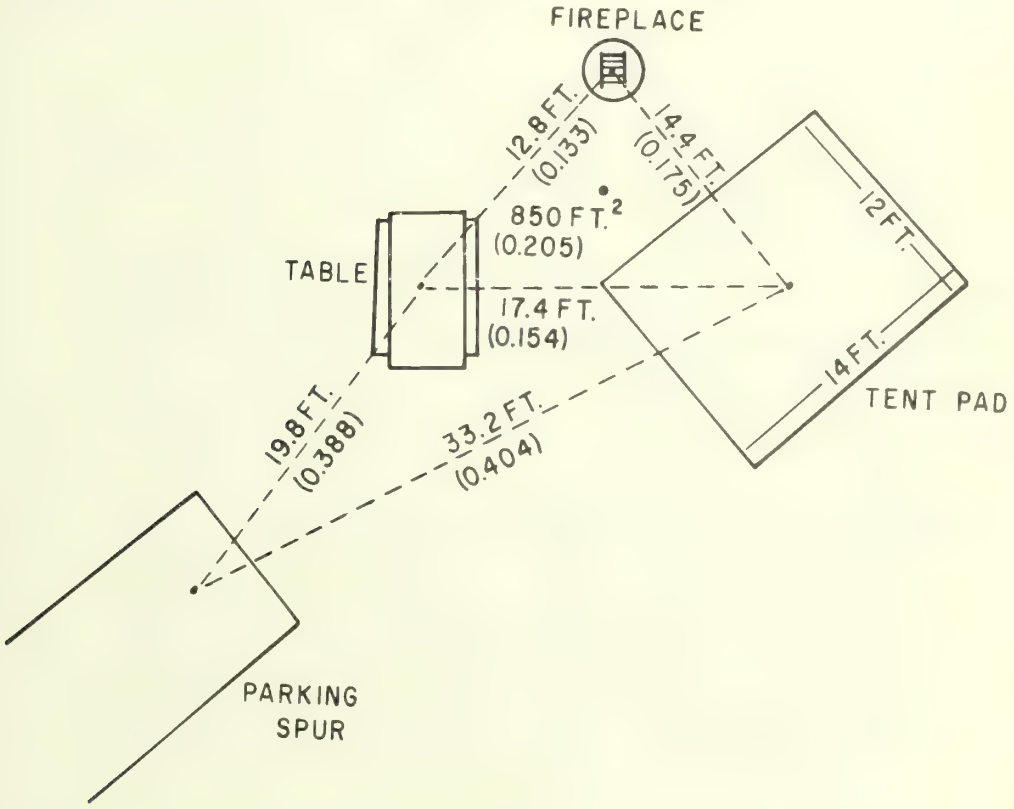

Figure 1.--Relative placement of campsite facilities with mean distances between facilities and coefficients of variation (in parentheses) of each mean.

Amount and Character of Vegetation

Vegetation was measured along two, perpendicular, intersecting, 100-foot lines transecting each campsite, with midpoints at the center of the campsite (the center of the triangle formed by the table, fireplace,

and tent pad). The location of one line was determined randomly between 0° and 90°. The second line was oriented perpendicularly to it. The ends of each transect line, plus the point of intersection at campsite center, were marked by iron stakes driven into the ground. Vegetation along the transects was measured annually in September. A 100-foot tape, divided into tenths of a foot, was stretched across the campsite center between the iron stakes marking the ends of each line. Vegetation was recorded by height strata (0 to 3 feet and 3 to 7 feet) and by species (grasses, hardwoods, conifers, thorny species, other woody species, and nonwoody species other than grasses). The lineal footage of the amount of each species of vegetation (and bare ground), in 0.1-foot increments, was determined along each transect by counting the number of 0.1-foot segments that were covered by each species. Density of cover within the segment was not determined; a partially covered 0.1-foot section received the same weight as a densely covered segment. These counts, divided by total length of line transects (two 100-foot lines), provided an estimate of percentage of ground cover for each stratum on each of the 21 study campsites.

From these data, the following information was obtained:

(1) Percentage of ground cover, by species--living vegetation between 0 and 7 feet high.

(2) Percentage of grass cover--including sedges and rushes.

(3) Percentage of screening cover--all vegetation between 3 and 7 feet high.

(4) Percentage of conifer cover--coniferous tree species of all heights.

(5) Percentage of cover of thorny species--species bearing thorns, e.g., greenbrier, black locust.

(6) Density of cover of understory vegetation--an index of density of understory vegetation. Counts were made separately for each species by 0.1-foot increments along each transect line and then added to produce total percentage of cover. The greater the degree of overlap by different species, the greater the density of total cover. The sum of all 0.1-foot segments with vegetation along the transect lines, divided by total number of segments, was the density index number.

(7) Percentage of cover of overstory trees--crown density of the overstory (higher than 7.0 feet) on each campsite as determined by ground mapping. The outline of all overstory crowns within a 50-foot radius of campsite center was mapped to scale, and the total area of crown cover was calculated. Area of crown cover, divided by total area within the 50-foot-radius circle, produced an estimate of percentage of overstory cover.

The greatest amount of variation was in amount of understory vegetation under 7 feet high, as shown in the following tabulation:

	Mean (percent)	Coefficient of variation (percent)
Ground cover	44.1	34.8
Grass cover	36.4	69.6
Screening cover	10.7	96.1
Conifer cover	11.3	107.8
Cover of thorny species	3.6	87.7
Density of cover of understory vegetation	.766	42.8
Cover of overstory trees[7]	60.0	41.0

Other Characteristics

Four other characteristics were measured for each campsite:

(1) Percentage of slope--general slope from the high side across the campsite center to its low side, as measured with an Abney level. Mean slope of the study campsites equaled 4.6 percent, and CV equaled 54.2 percent.

(2) Drainage--classified as well drained, moderately drained, or poorly drained.

(3) Aspect--general aspect as measured by a hand compass along the line from the high side across the campsite center to the low side. Mean aspect of the study campsites equaled 232°, and CV equaled 38.1 percent.

(4) Use on adjacent campsites--amount of use on the three nearest campsites without regard to distance and on adjacent campsites within a 100-foot radius.

Camper Preferences

Data on visitor preference were obtained by direct observation of campsite use, by personal interviews, and by self-administered questionnaires. The personal interviews and completed questionnaires were ob-

[7]Individual campsites received one of three cutting treatments in late 1964 and early 1965: (1) Light thinning to allow about 10 percent sunlight to reach the forest floor, (2) moderate thinning to allow about 40 percent sunlight, and (3) heavy thinning to allow about 70 percent sunlight.

tained from all available visitors to the campground on sample days, whether or not they occupied a study campsite. Data concerning campsite use were obtained only from visitors using the 21 study campsites which were opened in 1966 and for which information on vegetative cover was also available. Direct observations to determine user preferences could not be used in the analysis on days when all or most of the study campsites were occupied because, on such days, the visitor did not have a free choice of campsite. It was necessary, therefore, to collect data only on those days when the campground received below-average use and free choice of campsite was available.

An observer-interviewer obtained information on campsite use from May 28 through Labor Day during the period 1966 through 1970. At the beginning of each recreational season, 20 sampling dates were randomly drawn: 10 from weekends and holidays and 10 from weekdays. On each sample day, the observer walked through the campground every 2 hours from 9 a.m. to 9 p.m. and recorded whether a campsite was occupied by campers and, if occupied, the number of occupants. Campers on each campsite at 9 a.m., 11 a.m., 1 p.m., 3 p.m., 5 p.m., or 7 p.m. were assumed to remain for an entire 2-hour period. Thus, number of occupants multiplied by 2 gave an estimate of hours of use at each study campsite during each 2-hour period. The sum of the counts made from 9 a.m. through 7 p.m. provided an estimate of use at each campsite throughout the daylight hours. The 9 p.m. count was used to estimate the number of campers expected to occupy the campsite overnight. This count, multiplied by 12, provided an estimate of nighttime use. The sum of daylight and nighttime use provided an estimate of the number of hours of use during the 24-hour period from 9 a.m. on each sample day to 9 a.m. on the following day. This information was used to produce mean estimates of daily and season-long use for each campsite. Each sample day was classified as being less than average or equal to or above average in use. In addition, an estimate of number of hours of occupancy was derived for each campsite. Occupancy was estimated by considering a campsite to be occupied if it was being used by at least one person, without regard to total number of persons. Total hours of campsite occupancy were determined by the same procedures that were used for estimating mean daily and season-long use.

Upon completion of the visitor count on sampled days, the observer again circulated the campground and personally interviewed campers occupying the campsites. Each campsite was visited in turn, and the head of the household or group leader of each camping group was interviewed. The four-page questionnaire was designed to determine preferences of campers for certain physical characteristics of the campground and of individual campsites and to obtain socioeconomic information about the respondent and his family. Campers were interviewed only once on each sample day. A total of 1,133 usable questionnaires were completed during the 5-year period.

Upon completing the interview, each interviewed respondent was handed a short questionnaire and asked to complete it at his leisure. The camper was requested to walk through the campground, observe all of the 21 study campsites, and choose the most desirable and the least desirable.

He was asked to list on the questionnaire the numbers of the study campsites that he had chosen as the most desirable and as the least desirable and the reasons for his selections. Study campsites were identified by a numbered sign on a post at the end of each parking spur. A deposit box for the completed questionnaires was located at the exit to the campground. Two hundred and fifty-six usable questionnaires were returned during the period of study.

ANALYSIS AND RESULTS

Data analysis consisted of the following steps:

(1) Summarize socioeconomic characteristics of sampled campers.

(2) Summarize responses to the personal interview.

(3) Summarize responses to the self-administered questionnaire and relate specific responses to the characteristics of the campsites selected by respondents.

(4) Perform multiple-regression analysis to identify significant relationships between campsite characteristics and preferences of campers as expressed by their actual selection and use of specific campsites.

(5) Determine relationships between socioeconomic characteristics of campers and characteristics of campsites selected and used.

Socioeconomic Characteristics of Campers

More than 90 percent of the 414 families or groups of campers in the sample were from cities, towns, and rural areas within 200 miles of the campground, and 84 percent were from locations within a 100-mile radius. About 30 percent lived in or near towns of less than 5,000 population, 54 percent in or near towns of less than 20,000 population, and 64 percent in or near population centers with less than 100,000. Thirty-six percent lived in or near cities with population between 100,000 and 500,000. About 76 percent considered themselves urban residents, and the remainder said they lived in a rural area or on a farm outside city or town limits.

Average age of the head of the household was 38.2 years, with the following distribution:

Age (years)	Number	Percent
0-30	261	23.2
31-40	462	41.1
41-50	267	23.8
51-60	81	7.2
Above 60	52	4.7

Almost all respondents were married and were camping with their families. Twenty-five percent were accompanied by three or more children under 18 years of age, 32 percent by two children, 19 percent by only one child, and 24 percent had no children with them. Of those families that included children, the distribution of average age of child was as follows:

Average age (years)	Number	Percent
Less than 4.0	103	12.1
4.0-6.9	155	18.2
7.0-9.9	320	37.6
10.0-13.9	162	19.0
Greater than 13.9	112	13.1

Occupation of the head of the household was almost evenly distributed between blue-collar workers (48 percent) and white-collar workers (47 percent). Five percent were either unemployed or retired. Of the blue-collar workers, 49 percent were employed as craftsmen, foremen, and in allied occupations; and 45 percent were employed as equipment operators and unskilled laborers.[8] Of the white-collar workers, 23 percent were proprietors, managers, or officials; 29 percent were in clerical, sales, and similar occupations; and 39 percent were professionals, including teachers. Average family income was $8,868. Only 10 percent had annual incomes of less than $5,000, and 7 percent had incomes in excess of $15,000. Forty percent had completed 11 to 12 years of schooling, 39 percent had completed 13 to 16 years, and 10 percent had completed more than 16 years.

Personal Interview

Over the 5-year study period, 1,133 usable interviews were obtained from campers who occupied a campsite on sampled days. The major objective of the structured interview was to obtain a broad view of campers' preferences for campsite design and type of facility provided.[9] The major question asked was: "Which campsite characteristics are most important when you look for a campsite of your choice?" The question provided respondents with 14 categories, including a "no preference" and a "free response" category. Campers were asked to choose the three campsite characteristics most important to their camping experience and to rank them in order of preference.

[8]Classifications are based on standard classes of occupations as used by the U. S. Department of Commerce, Bureau of the Census.

[9]Supplementary information on camper preferences about specific facilities can be obtained by writing the Southeastern Forest Experiment Station, P. O. Box 2570, Asheville, North Carolina 28802.

The characteristics receiving the largest total response, and thus assumed to be the most important to campers, were: (1) nearness to comfort station, (2) amount of shading, (3) nearness to a community water hydrant (no individual spigots were available), (4) nearness to lake, and (5) privacy from other campers. The percentage of respondents selecting these campsite characteristics as first, second, and third choices, and total response, are shown in the following tabulation:

Characteristic	First choice (percent)	Second choice (percent)	Third choice (percent)	Total response (percent)
Nearness to comfort station	34.2	38.4	10.6	83.2
Amount of shading	38.8	16.7	21.1	76.6
Moderate	22.0	10.7	15.8	48.5
Full	16.3	5.4	4.4	26.1
Almost none	.5	.6	.9	2.0
Nearness to community water hydrant	7.9	29.6	29.7	67.2
Nearness to lake	12.8	7.5	15.1	35.4
Privacy from other campers	4.5	2.4	8.9	15.8

Other characteristics listed, in descending order of total response, were: (1) absence of understory vegetation--5.9 percent, (2) location close to other campers--2.8 percent, (3) closeness to campfire theater--2.5 percent, (4) presence of understory vegetation--2.0 percent, and (5) closeness to play area--2.0 percent. Only 3.2 percent indicated a characteristic other than those listed on the questionnaire (free choice), and another 3.2 percent indicated that they had no particular preference.

Two additional questions relating to amount of campsite shading were asked: (1) "Have you noticed a difference in number of trees or amount of shading on different campsites?" and (2) "Do you favor or oppose tree cutting to open up campsites to sunlight?" Only 17 percent of the respondents indicated they had not noticed the different amounts of shading. Eighty-five percent responded that they opposed cutting trees on campsites, and 8 percent were indifferent to tree cutting.

In answer to a question concerning campsite screening, 84 percent favored a limited amount of small vegetation that would serve to screen their campsites from the view of others.

Campers were asked to express their preferences concerning location of the campsite relative to a comfort station, a community water hydrant, and other campsites. Few campers desired to be closer than 100 feet to a comfort station, but 76 percent preferred locations within 100 feet of a community water hydrant. Average preferred distances were about 192 feet from campsite to comfort station and about 115 feet to a water hydrant. Rate of response to the five distance categories listed on the questionnaire is shown below:

Preferred distance to facility (feet)	Response concerning comfort station (percent)	Response concerning water hydrant (percent)
50	7.0	41.7
100	34.5	34.7
200	41.0	16.6
400	13.0	4.8
800	1.9	.7
No expressed preference	2.6	1.5

When asked whether the approximate minimum spacing of 80 feet between campsites at Indian Boundary Campground was too close, about right, or not close enough, 74 percent replied that existing spacing was about right. Twenty-four percent thought spacing should be greater than 80 feet, 1 percent indicated that spacing should be closer than 80 feet, and 1 percent had no expressed preferences.

In response to a question about fireplaces, 79 percent indicated that a metal grill was preferable to a rock-masonry fireplace or any other type. Surprisingly, 11 percent indicated that grills were unnecessary. Ten percent had no expressed preference.

In response to a question about size of tent pads, 86 percent felt that the 12- by 14-foot tent pad provided at Indian Boundary Campground was adequate.

Self-Administered Questionnaire

Thirty major categories of response were identified from among the reasons given for selecting specific campsites as most desirable and least desirable. Most respondents listed two or more reasons for each of their selections. However, because there was no differentiation as to which of these reasons the respondent considered more important, all responses received equal weight in summarizing the questionnaire results.

Most of the response categories were easily identifiable with measurable characteristics of the campsites. Because each response referred

to a particular study campsite whose characteristics had been quantified, a specific value could be assigned to each response for both desirable and undesirable campsites. By aggregating values of each of the measured characteristics to which the response referred, mean values of characteristics of desirable and undesirable campsites were computed for each response category. These means for each characteristic were then statistically compared by Student's t test. In some cases, more than one physical characteristic was used for a single response category, depending on the broadness in the descriptiveness of the category. The results of comparisons for response categories that received at least 10 percent of the total number of responses (256) are presented in table 1.

Table 1.--Summary of results of the self-administered questionnaire and means of the campsite characteristics referred to by respondents

Campsite characteristic	Responses	Mean value of characteristic		Level of significant difference
		Desirable campsites	Undesirable campsites	
	Number			
Amount of shade:	172			
Percent of canopy closure		80.0	38.5	0.001
Nearness to comfort station:	72			
Distance in feet		178.3	187.2	NS
Openness (amount of vegetation):	69			
Density index of vegetative cover under 7 feet		.466	.868	.001
Percent of grass cover		19.6	55.2	.001
Campsite drainage:	61			
Percent of campsites with good drainage		83	--	[1].001
Percent of campsites with poor drainage		--	80	
Nearness to community water hydrant:	54			
Distance in feet		104.8	115.4	NS
Nearness to other campsites:	54			
Mean distance in feet to closest three		119.4	108.6	.001
Levelness of campsite:	44			
Percent of slope		4.9	5.4	NS
Location of table relative to parking spur:	25			
Distance in feet		19.8	28.0	.100

[1] The independence of the distribution of responses between the two drainage classes was tested with chi-square as the criterion. The resulting chi-square was 43.94 with 2 degrees of freedom.

To aid the reader in interpreting this table, the following discussion of the first characteristic listed--amount of shade--is provided. A total of 172 responses indicated that specific campsites were most or least desirable because of the amount of shade afforded by existing overstory cover. On study campsites which respondents indicated were most desirable, the average amount of overstory closure (i.e., percentage of direct sunlight blocked out) was 80.0 percent. On campsites listed as least desirable, the mean overstory closure was only 38.5 percent. These means were significantly different at the 0.001 level of probability.

The meaning of other relationships shown in table 1 is given below:

(1) Among campers to whom shading is important, shaded campsites are preferred to sunny campsites within the sample range of 30 to 90 percent canopy closure.

(2) Campsites having little understory vegetation are preferred to those having relatively more understory. Campers are apparently willing to sacrifice grass cover, in addition to other understory vegetation, to have shaded campsites.

(3) Well-drained campsites are preferred to poorly drained campsites.

(4) Campsites that are farther removed from the nearest three campsites are preferred to those closer to other campsites. The sample range was 73 to 132 feet.

(5) Table location was important to some campers. The location of the table relative to spur orientation was also tested, and no significant differences were found.

(6) Distances between campsite and comfort station, and between campsite and community water hydrant, were not significantly different between the desirable and the undesirable campsites.

(7) Slope of campsite was not significantly different.

Other reasons mentioned, but not as frequently, for campsite selections were as follows:

Campsite characteristic	Number of responses	Percent of total respondents
Campsite is spacious	23	9.0
Adequate screening	12	4.7
Near campfire theater	9	3.5
Near lake	9	3.5
Well-located fireplace	6	2.3
Well-located tent pad	6	2.3

Observations of Campsite Occupancy

Multiple-regression analysis was used to determine which of the measured characteristics were significantly associated with campers' selections of campsites. This step in the overall analysis was an attempt to determine the important and often-omitted link between what users say they prefer and what they demonstrate that they prefer, i.e., verification of the results of the personal interview and self-administered questionnaire. The approach was to observe the 21 study campsites in order to determine how frequently and for how long each was used by a camping family or group and then to evaluate the effects of the characteristics of the campsites on variation in the observed frequencies. The specific dependent variable, herein called occupancy, was the average number of hours per day that a study campsite was occupied by a camping group of one or more persons; observations were made only on days when total campground use was less than the seasonal average for daily use.

Occupancy of campsite, rather than total use, was selected for two reasons. First, on days of less than average use, campers had a greater number of campsites from which to choose and, therefore, a greater opportunity to express true preferences than would have been possible on days of heavier use when a larger number of campsites was occupied. Second, occupancy is a better indicator of the expressed preferability than total hours of use because this factor assigns equal weight to occupied campsites regardless of the number of occupants, i.e., selection of a campsite by one person or five persons is an equal expression of the desirability of that campsite. During the study period, average campsite occupancy on days of light use was estimated to be 5.79 hours per day. Average hours of use on days of heavy use was 14.96. Average time that a study campsite was occupied, without regard to the amount of use that the entire campground received, was 8.76 hours per day.

Multiple-Regression Analysis

Several campsite characteristics, in addition to those indicated by responses to the self-administered questionnaire, were used as independent variables in the multiple-regression procedure.[10] Because several of these stood in close linear relation to one another (multicollinearity) and yet had meaning in describing what the camper considered when selecting a campsite, an iterative process was followed in regressing these variables on campsite occupancy in order to avoid an arbitrary allocation of explanatory power between them.

[10]Twenty-seven variables were considered. Fourteen of these are discussed in the following pages. The others include: distance to fishing pier, swimming beach, campfire theater, playfield, nearest campsite, and nearest three campsites; area between table, tent pad, fireplace, and end of parking spur; location of campsite facilities relative to long axis of parking spur; distance from end of parking spur to campsite center; percentage of campsite covered by conifers under 7 feet high; percentage of thorn-bearing vegetation under 7 feet high; density index of understory vegetation; and a dummy variable for well-drained campsites.

To minimize the multicollinearity problem, a matrix of simple correlations, including all the explanatory variables, was run to indicate which of the independent variables had strong collinear relationships. Several models were then formulated so that no two independent variables in any one model had a simple correlation greater than 0.8. Each of these models was then run separately by a multiple-regression procedure.

Eleven variations of the basic model were run by stepwise multiple regression at a threshold F-value equal to 2.77 (approximately the 10-percent level of confidence with 1 and 95 degrees of freedom) for the separate effects of each variable. The analysis included 105 observations.

The explanatory power of the models, as indicated by the multiple correlation coefficient (R), ranged from 0.53 to 0.74. The model with R equal to 0.74 is summarized below. The numbers in parentheses below the partial regression coefficients are standard errors of the respective coefficients.

$$\begin{aligned}\text{Occupancy} = {} & 10.173 - \underset{(0.253)}{0.597}\ (\text{slope}) + \underset{(1.0670)}{3.047}\ (\text{aspect}) \\ & + \underset{(0.008)}{0.013}\ (\text{distance to comfort station}) \\ & + \underset{(0.007)}{0.014}\ (\text{distance to hydrant}) \\ & - \underset{(0.003)}{0.012}\ (\text{distance to shoreline}) \\ & + \underset{(0.024)}{0.081}\ (\text{percent of canopy closure}) \\ & - \underset{(0.002)}{0.006}\ (\text{square feet between table, tent pad, and fireplace}) \\ & - \underset{(0.019)}{0.053}\ (\text{largest angle of triangle between table, tent pad, and fireplace}) \\ & - \underset{(0.0001)}{0.0006}\ (\text{use on campsites within 100-foot radius}) \\ & + \underset{(0.0001)}{0.0008}\ (\text{use on nearest three campsites}).\end{aligned}$$

Variables sigrificantly correlated with campsite occupancy in the 10 other regression models were: percent covered by 3- to 7-foot-high

vegetation ($b \approx 0.0101$, $SE_b \approx 0.0033$),[11] percent covered by understory not over 7 feet high ($b \approx -0.0099$, $SE_b \approx 0.0024$), percent covered by grass ($b \approx -0.0070$, $SE_b \approx 0.0015$), and a dummy variable for poorly drained campsites ($b \approx -3.838$, $SE_b \approx 0.813$).

The partial regression coefficients indicate the average change in mean number of hours per day that campsites were occupied per unit change in the independent variable holding all other independent variables constant. Thus, these coefficients indicate the average effect of each variable or campsite characteristic on the mean number of hours per day each of the study campsites was occupied. To the extent that occupancy reflects the free expression of camper preferences, these coefficients can be interpreted as the average contribution of the characteristics to the overall desirability of the campsites to Indian Boundary campers in the aggregate.

Results of the Analysis

The following inferences concerning preferences of campers for the physical characteristics of campsites may be drawn from results of the multiple-regression analysis:

(1) The positive regression coefficient for the variable concerning percentage of canopy closure indicates that, if all campsites were the same except for differing amounts of canopy cover, those campsites with more overstory cover, and thus offering more shade, would be more desirable than those with less canopy.

(2) Campsites that are poorly drained and that stay wet after a rain are less desirable than well-drained campsites.

(3) A campsite situated within approximately 85 feet (the mean distance between adjacent campsites) of other campsites which receive heavy use is less desirable than one situated within 85 feet of campsites which receive lighter use.

(4) The mean distance between any one campsite and the three nearest campsites was 107 feet. At this greater distance, in comparison with that to the nearest single campsite, the favored campsite is one whose neighboring campsites receive heavy use. Thus, heavy use very near the campsite is undesirable, whereas heavy use at greater distances is preferred.

[11] In these equations, b stands for the partial regression coefficient, and SE_b stands for the standard error of the partial coefficient. F equals the ratio $\left(\frac{b_i}{SE_{b_i}}\right)^2$.

(5) Level campsites are more desirable than more steeply sloped campsites.

(6) East-facing campsites (those whose slope face has a compass bearing between 0° and 179°) are more desirable than west-facing campsites.

(7) Campsites with relatively sparse understories under 7 feet high are more desirable than densely vegetated campsites.

(8) The more desirable campsites have a larger amount of 3- to 7-foot-high vegetation that could effectively serve as screening from adjacent campsites. This finding is not in direct conflict with that concerning the previous variable. Whereas the present variable includes only vegetation between 3 and 7 feet high, the previous variable also includes vegetation less than 3 feet high, much of which is very rank on many campsites.

(9) The more desirable campsites have less grass cover. This preference probably does not indicate a desire for less grass, but rather the strong desire for shaded sites. Shading precludes the establishment of a good cover of indigenous grass species. In addition, the small amount of grass cover on the more desirable campsites probably reflects greater loss of grass as a result of heavy trampling.

(10) Spacing of the campsite facilities such that the area between the table, tent pad, and fireplace is relatively small is more desirable than spacing which results in a large area between facilities.

(11) Placement of the campsite facilities such that the table, tent pad, and fireplace are more nearly clustered rather than situated in a line is more desirable. If the findings for this and the previous variables are considered simultaneously, it appears that Indian Boundary campers prefer that campsite facilities be placed close together about a central point.

(12) Campsites located closer to the lake shoreline are more desirable than those farther removed.

(13) Campsites located farther from a comfort station are more desirable than those closer to one.

The multiple-regression analysis, in which campsite occupancy was used as an indicator of the aggregate desirability of a campsite, agreed closely with the results of the self-administered questionnaire, i.e., campers selected and occupied campsites which they said were desirable.

Relationship Between Camper and Campsite Characteristics

A one-way analysis of variance was used to test for relationships between the characteristics of campsites and the previously discussed socioeconomic characteristics of the 414 families interviewed between 1966 and 1970. The analyses revealed that almost none of the means of campsite characteristics were significantly different among campers with different socioeconomic characteristics. In fact, only eight of the 140 tests indicated significantly different means at the 0.05 level of probability. It is apparent that, for this sample of campers, the socioeconomic characteristics measured have little relevance in explaining why certain campsites were selected and are of little usefulness in explaining camper preferences.

SUMMARY AND CONCLUSIONS

There was a comforting amount of parallelism in the findings from the different methods used to determine campers' preferences regarding physical characteristics of campsites. This parallelism lent an important degree of credibility to the results. The investigation revealed a set of preferences that seemed to be structured around a few general characteristics of campsites. A summary and brief discussion of the significant characteristics follow in approximate order of importance.

(1) The location of a comfort station was one of the most important factors considered in selecting a campsite. On the basis of the magnitude of response, location of a comfort station ranked highest among all of the characteristics listed in the questionnaire used in the personal interviews and second highest among those listed in response to the self-administered questionnaire. In addition, the importance of this variable in campsite selection was verified by the multiple-regression analysis. The regression analysis revealed a positive correlation, indicating that a campsite located farther away from the comfort station, though still easily accessible, is more desirable than a campsite too near a comfort station. The desire is for comfort stations neither too close to nor too far from campsites. Campers indicated an optimum spacing of approximately 200 feet between comfort station and campsite.

(2) Campsite shading appeared to rank about equally with location of a comfort station as an important characteristic. This characteristic received the largest percentage of response from the self-administered questionnaire and the second largest response to the personally administered questionnaire. Multiple-regression analysis revealed that amount of shade was

significantly and positively correlated with average hours of daily occupancy of the campsite. Results from all three sources of information indicate that moderate to heavy shade is most preferred, almost-full shade is ranked second, and campsites having little shade are least preferred. The range in canopy closure needed to produce the most desired amount of shade is between 60 and 80 percent.

(3) Campers placed considerable importance on accessibility of drinking water in selection of a campsite. This characteristic ranked third in percentage of responses to the interview and fifth in responses to the self-administered questionnaires. Also, the partial correlation between distance from campsite to a community water hydrant, as indicated by actual campsite occupancy, indicated the importance of this characteristic. Most campers preferred to be located about 100 feet from one of the community water hydrants. Few desired to be within 50 feet or over 100 feet away. It should be noted that this finding applies only to community water hydrants and that no inferences should be drawn concerning the alternative of locating a water spigot at each campsite.

(4) Understory vegetation plays an important dual role in campground management. Maintenance of ground-level species, such as grasses and shrubs, is important to protection of developed recreational sites from soil erosion and other types of deterioration. Understory vegetation is also cited as important to enhancement of esthetics and amenity values of the site. Yet, campers at Indian Boundary Campground informed us that they preferred minimal understory vegetation on campsites. In response to the personally administered questionnaire, campers selected campsite openness as the third most important characteristic. This response was substantiated by a comparison of the average density of all understory vegetation and grass cover on campsites selected as most desirable and least desirable. A negative sign on the partial coefficients for percentage of understory and grass cover in the regression analysis confirmed camper preference for campsites with sparse understory cover.

(5) Adequacy of campsite drainage was the fourth most frequently mentioned characteristic among those listed by respondents to the self-administered questionnaire and was significantly correlated with amount of campsite occupancy, as indicated by the regression analysis.

(6) Questionnaire and regression results indicated that relatively level campsites are preferred to more steeply sloped campsites.

(7) Arrangement of facilities within the campsite was important to campers. Respondents desired the table to be placed relatively near the parking spur and that the table, tent pad, and fireplace be placed about a central point, rather than in a straight line.

The fact that this study was not replicated is not believed to be a serious shortcoming concerning the significance of the findings. Although the preferences of users probably vary from one geographical area or cultural background to another, it is very likely that most campers have personal preferences for those physical features that closely parallel the findings revealed in this study. With average costs of construction running about $3,000 per campsite in the Southern Appalachians, it is important that recreation managers, planners, and designers consider design standards that utilize available information on the preferences of users. In this way, the public's satisfaction may be increased and use loads distributed more evenly over the entire recreational complex. Information concerning preferences of users is especially important to developers and owners of private recreational areas because a satisfied clientele will determine whether the areas succeed or fail. Additional studies should be conducted in other geographical locations in order to provide quantitative results comparable with those presented here and with broad and practical application.

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Cordell, Harold K., and James, George A.
1972. Visitors' preferences for certain physical characteristics of developed campsites. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-100, 21 pp.

Visitors to a Southern Appalachian campground were studied during summer camping seasons from 1966 through 1970 to determine their preferences for such things as spacing between campsites, comfort stations, and water hydrants; amount of understory and overstory vegetation; and other physical characteristics of the site. To enhance the credibility of the results, three data sources were used to determine visitor preferences: personal interviews, self-administered questionnaires, and observations of actual campsite occupancy. The most important characteristics were location of the campsite relative to a comfort station and water hydrant and amount of shading and understory vegetation on the campsite.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Growth and Yield of Thinned Yellow-Poplar

by

Donald E. Beck and Lino Della-Bianca

APR 28

Cover photo: This thinned stand of yellow-poplar is 67 years old, is growing on site index 97 land, and has 90 square feet of basal area per acre. Stands such as this are capable of producing large quantities of high-value products.

Growth and Yield of Thinned Yellow-Poplar

by

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and

Lino Della-Bianca, Silviculturist

Asheville, North Carolina

Diameter distributions and yields for various combinations of site index, age, and density for unthinned and largely undisturbed stands of yellow-poplar (Liriodendron tulipifera L.) have been presented by McGee and Della-Bianca (1967) and Beck and Della-Bianca (1970). Their results were based on the initial measurements of a network of permanent sample plots throughout the southern Appalachians. In this paper we present equations for predicting basal-area growth and cubic-foot volume growth and yield in stands thinned to various levels of basal area. These results are based on measurements of the permanent plots taken 5 years after the initial thinnings.

METHODS

Plot Selection

Data for this study were obtained from 141 circular, $\frac{1}{4}$-acre plots established in the Appalachian Mountains of North Carolina (93 plots), Virginia (31 plots), and Georgia (17 plots). To be included in the study, the plots had to contain 75 percent or more yellow-poplar in the overstory, be free from insect and disease damage, and show no evidence of past cutting. All plots came from even-aged stands ranging in age from 17 to 76 years. Site index ranged from 74 to 138 feet. Site index at age 50 was determined with an equation (Beck 1962) that used average height and age of the five tallest yellow-poplar trees in each plot. Initial basal area varied from 44 to 208 square feet per acre.

Thinning

To obtain a range of basal area for various site-age combinations, each plot was thinned at the time of installation. Prior to thinning, each plot was assigned to a basal-area class and then thinned to the midpoint of a randomly selected lower basal-area class. For example, stands

with 91 through 110 square feet of basal area per acre would be assigned to the 100-foot class, then thinned to the 80-, 60-, or 40-square-foot basal-area class.

Low thinning (Society of American Foresters 1964) was used to reduce the stand basal area. Suppressed trees were cut first, then thinning was extended into higher crown classes as needed to obtain the desired residual density in well-spaced trees. The effect of this procedure was to reduce the range of tree diameters and concentrate the growing stock in the dominant and codominant crown classes. A $\frac{1}{2}$-chain isolation strip around each $\frac{1}{4}$-acre plot was thinned to the same residual basal area as the plot. All trees and shrubs less than 4.5 inches d.b.h. were cut to ground level to eliminate competition from stems other than residual trees (fig. 1). Species other than yellow-poplar were generally cut in thinning, except in a few plots other species were retained to avoid irregular spacing among residual yellow-poplar trees. Stand densities immediately after thinning ranged from 40 to 160 square feet of basal area per acre in trees 4.5 inches d.b.h. and over. Table 1 shows distribution of plots at the beginning of the 5-year measurement period by site index, age, and residual stand density.

Figure 1.--A 35-year-old yellow-poplar stand, site index 99, after thinning to 42 square feet or basal area per acre. All trees and shrubs less than 4.5 inches d.b.h. were cut to ground level.

Table 1.--Distribution of yellow-poplar plots by site index, age, and residual basal area after thinning

Site index (feet at 50 years)	Age class	Residual basal area (sq. ft./acre)							Total
		40	60	80	100	120	140	160	
	Years	Number of plots							
80	50	--	2	--	--	--	--	--	3
	60	--	--	--	--	--	--	--	
	70+	--	--	1	--	--	--	--	
90	20	--	--	--	--	--	--	--	16
	30	3	1	--	--	--	--	--	
	40	1	1	1	--	--	--	--	
	50	--	--	1	--	--	--	--	
	60	--	1	3	--	--	--	--	
	70+	--	--	--	1	3	--	--	
100	20	2	--	--	1	--	--	--	32
	30	2	--	1	--	--	--	--	
	40	1	--	1	1	--	--	--	
	50	--	3	3	1	1	--	--	
	60	1	2	1	1	3	--	1	
	70+	--	1	2	3	--	--	--	
110	20	--	--	--	1	--	--	--	52
	30	1	2	1	1	--	--	--	
	40	2	2	3	2	2	--	--	
	50	1	1	3	1	3	2	1	
	60	--	3	5	2	3	3	--	
	70+	--	1	2	2	1	1	--	
120	20	--	1	--	--	--	--	--	26
	30	3	1	3	2	2	--	1	
	40	1	2	1	2	--	--	--	
	50	--	--	--	1	2	--	--	
	60	--	--	--	--	1	1	1	
	70+	--	--	--	1	--	--	--	
130	20	1	--	--	--	--	--	--	10
	30	--	1	--	1	3	--	--	
	40	1	--	--	1	2	--	--	
	50	--	--	--	--	--	--	--	
	60	--	--	--	--	--	--	--	
	70+	--	--	--	--	--	--	--	
140	20	--	--	--	--	--	--	--	2
	30	--	--	--	1	--	--	--	
	40	--	--	--	--	--	--	--	
	50	--	--	--	--	--	--	--	
	60	--	--	--	--	--	--	--	
	70+	--	--	1	--	--	--	--	
Total		20	25	33	26	26	7	4	141

Volume Estimates

Volumes and basal areas were computed when the plots were thinned and again after five growing seasons. All stems, 4.5 inches d.b.h. and over, were measured by diameter tape and tallied to the nearest 0.1 inch. Total tree height was measured for the first tree and every tenth tree thereafter in each 1-inch diameter class. For each plot, a height-diameter equation of the general form log ht. = $a + b(\text{d.b.h.})^{-1}$ was fitted by least squares to the height and diameter data obtained from every tenth tree; the results were used to estimate total height for each tree in the plot. The volume in individual trees was determined from existing equations (Beck 1963, 1964). Plot volumes were computed from these data.

Analysis

The analysis was accomplished by using the system of compatible growth and yield models proposed by Clutter (1963) and later extended and refined by Sullivan and Clutter (1972). These models allow prediction of basal area and volume at some projected age when site index, initial age, and basal area are given. The projection model we used in this study is:

$$\ln Y_2 = b_0 + b_1(S^{-1}) + b_2(A_2^{-1}) + b_3(A_1/A_2)(\ln B_1) + b_4(1 - A_1/A_2) + b_5(S)(1 - A_1/A_2) \quad (1)$$

Where: Y_2 is stand volume at some projected age A_2; S is site index; B_1 is present basal area; A_1 is present age; and ln indicates the natural (Naperian) logarithm.

When $A_2 = A_1 = A$, i.e., the projection period is zero years, and $B_1 = B_2 = B$, then equation (1) reduces to the general yield model or stand volume equation:

$$\ln Y = b_0 + b_1(S^{-1}) + b_2(A^{-1}) + b_3(\ln B) \quad (2)$$

The yield projection model, equation (1), was essentially derived by substituting a basal-area projection equation for the basal-area term in a stand-volume equation, such as equation (2). Therefore, inserting $\ln Y_2$, A_2, and $\ln B_2$ into equation (2) and getting the resulting expression equal to the right side of equation (1), then solving the equality for $\ln B_2$ gives the model for projected basal area B_2 at projected age A_2:

$$\ln B_2 = (A_1/A_2)(\ln B_1) + (b_4/b_3)(1 - A_1/A_2) + (b_5/b_3)(S)(1 - A_1/A_2) \quad (3)$$

By taking the first derivative of the basal-area yield model, equation (3), with respect to age, the equation for basal-area growth is obtained:

$$dB/dA = (B)(A^{-1})[(b_4/b_3) + (b_5/b_3)(S) - (\ln B)] \quad (4)$$

Likewise, the first derivative of the cubic-foot yield model, equation (2), gives the cubic-foot growth model:

$$dY/dA = y^*[-b_2(A^{-2}) + b_3(B^{-1})(dB/dA)] \quad (5)$$

The variable y^* is total cubic-foot yield calculated with equation (2). The parameters of the basic yield model, equation (1), were estimated by the least squares method using total cubic-foot stand volume as the yield observation. In fitting the equation, data taken following thinning at plot establishment and again 5 years after thinning were combined, for a total of 282 observations. In this procedure, the data taken at establishment are viewed as observations on the yield projection function in equation (1) with projection period = zero, so $A_2 = A_1$. The data taken at remeasurement are viewed as observations on the same yield function after a 5-year projection period, i.e., $A_2 = A_1 + 5$. In fitting the least squares regression, the two sets are treated as independent observations when they are not. The consequences of this for statistical inference were not serious in the case examined by Sullivan and Clutter (1972). Readers interested in detailed justification for the procedure are referred to this paper.

RESULTS

All independent variables of the yield model were highly significant (table 2); hence, projected total cubic-foot yield per acre was estimated by:

$$\begin{aligned} \ln Y_2 = {} & 5.36437 - 101.16296(S^{-1}) - 22.00048(A_2^{-1}) \\ & + 0.97116(A_1/A_2)(\ln B_1) + 3.71796(1 - A_1/A_2) \\ & + 0.01619(S)(1 - A_1/A_2) \end{aligned} \quad (6)$$

Table 2.--Analysis of variance for projected total cubic-foot yield per acre of yellow-poplar

Source	d.f.	SS	MS	F
Effect of (S^{-1})	1	6.02912		2,084.16**
Added effect of (A_2^{-1})	1	29.56379		10,219.67**
Added effect of $(A_1/A_2)(\ln B_1)$	1	11.70101		4,044.83**
Added effect of $(1 - A_1/A_2)$	1	16.08572		5,560.54**
Added effect of $(S)(1 - A_1/A_2)$	1	0.04179		14.45**
Error	276	0.79842	0.00289	
Total	281	64.21985		

**Indicates significance at .01 level of probability.

Growth and yield equations derived directly from the fitted regression equation (6) are:

Total cubic-foot yield per acre when $A_2 = A_1 = A$:

$$\ln Y = 5.36437 - 101.16296(S^{-1}) - 22.00048(A^{-1}) + 0.97116(\ln B) \quad (7)$$

Projected basal-area yield per acre:

$$\ln B_2 = (A_1/A_2)(\ln B_1) + 3.82837(1 - A_1/A_2) + 0.01667(S)(1 - A_1/A_2) \quad (8)$$

Instantaneous basal-area growth per acre per year:

$$dB/dA = (B)(A^{-1})[3.82837 + 0.01667(S) - (\ln B)] \quad (9)$$

Instantaneous total cubic-foot growth per acre per year:

$$dY/dA = y^*[3.71796(A^{-1}) + 0.01619(S)(A^{-1}) - 0.97116(A^{-1})(\ln B) + 22.00048(A^{-2})] \quad (10)$$

With $y^* = Y$ computed by equation (7).

The values of the dependent variables for equations (6) through (10) were solved for each of 141 plots, and residuals were plotted against each of the independent variables. There were no discernible trends of the residuals with site index, age, or basal area. Curves of estimated values for specified combinations of site index, age, and density were logical in form and reasonable in predicted values. Comparisons of actual and estimated yellow-poplar growth and yield are summarized in table 3.

Estimates from equations (6) through (10) for selected values of the independent variables are shown in the Appendix (tables 5 through 7 and figures 8 and 9). Table 5, from equation (7), gives estimates of present yellow-poplar stand volume in total cubic feet per acre for various combinations of site index, age, and stand basal area. Figures 8 and 9 (from equations (8) and (6), respectively) show the projected development of basal area and total cubic-foot volume in yellow-poplar stands with prescribed initial basal areas. Tables 6 and 7 (from equations (9) and (10), respectively) show instantaneous basal-area growth and total cubic-foot growth per acre per year for given site-index, age, and basal-area values.

DISCUSSION

The equations presented in this paper are a first approximation to the growth and yield response surfaces for thinned yellow-poplar stands. The fit of the yield equations to the data compares favorably with that re-

Table 3.--Comparisons of observed and estimated yellow-poplar growth and yield per acre after thinning

Equation number	Data set	Average observed growth or yield	Average difference between observed and estimated	Variation explained by equation
				Percent
(7)	First period total cubic-foot measurements used as yield observations	3,778	+38.8	98.7
(7)	Second period total cubic-foot measurements used as yield observations	4,560	+14.4	99.3
(6)	Second period total cubic-foot volumes as projected from first period measurements	4,560	+54.7	98.3
(10)	Instantaneous total cubic-foot growth per year	156	+17.2	33.4
(8)	Second period basal area (sq. ft./acre) as projected from first period measurements	97	+0.8	98.5
(9)	Instantaneous basal-area growth (sq. ft./acre/year)	2.4	+0.06	47.2

ported for loblolly pine by Sullivan and Clutter (1972). The fit of the basal-area growth and cubic-foot volume growth equations is also comparable to that found for loblolly pine at the first 5-year remeasurement (Wenger et al. 1958). Experience with other tree species has shown that we can expect the precision of growth and yield predictors to improve as we accumulate additional cutting cycles and remeasurements in our permanent sample plots. Until additional data become available, however, the equations and graphs presented here are useful in estimating the effects of varying initial densities on basal-area growth, total cubic-foot growth, and total cubic-foot production.

Figures 2 and 3, from equations (9) and (10), illustrate the relationship of basal-area growth and total cubic-foot volume growth to initial basal area of thinned yellow-poplar stands over a range of site indices at a given stand age. The relatively flat curve with culmination of growth at progressively higher basal areas as site quality increases is similar to that found for loblolly pine (Nelson et al. 1961). Basal-area growth, in particular, changes but little over a wide range of residual basal areas. For example, a 40-year-old yellow-poplar stand on site index 110 produces basal area at better than 95 percent of its maximum rate for basal areas between 70 and 140 square feet per acre.

Figures 2 and 3 also point up the need to know site quality of yellow-poplar stands and to manage them accordingly. For example, on site index 90 land, maximum basal-area growth in a 40-year-old stand is

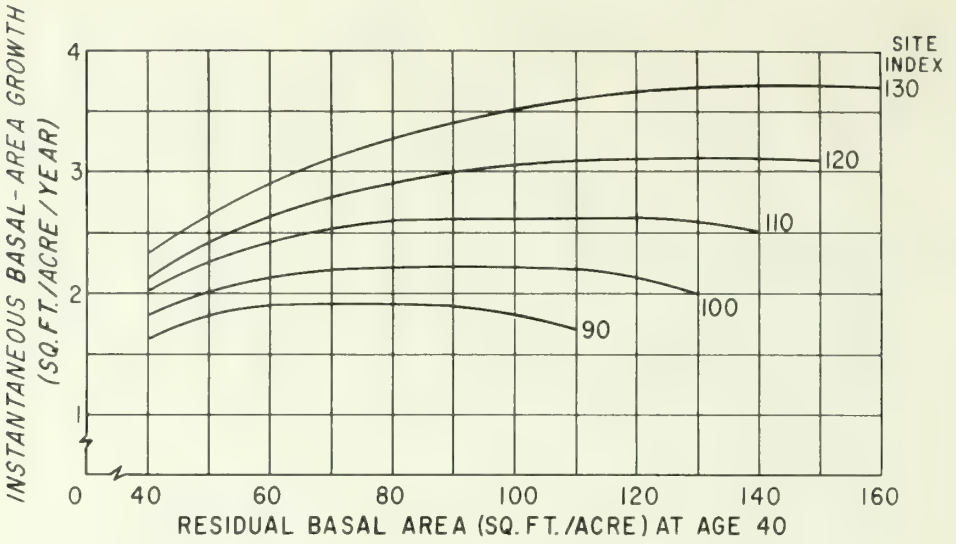

Figure 2.--Instantaneous basal-area growth in relation to site index and residual basal area at age 40.

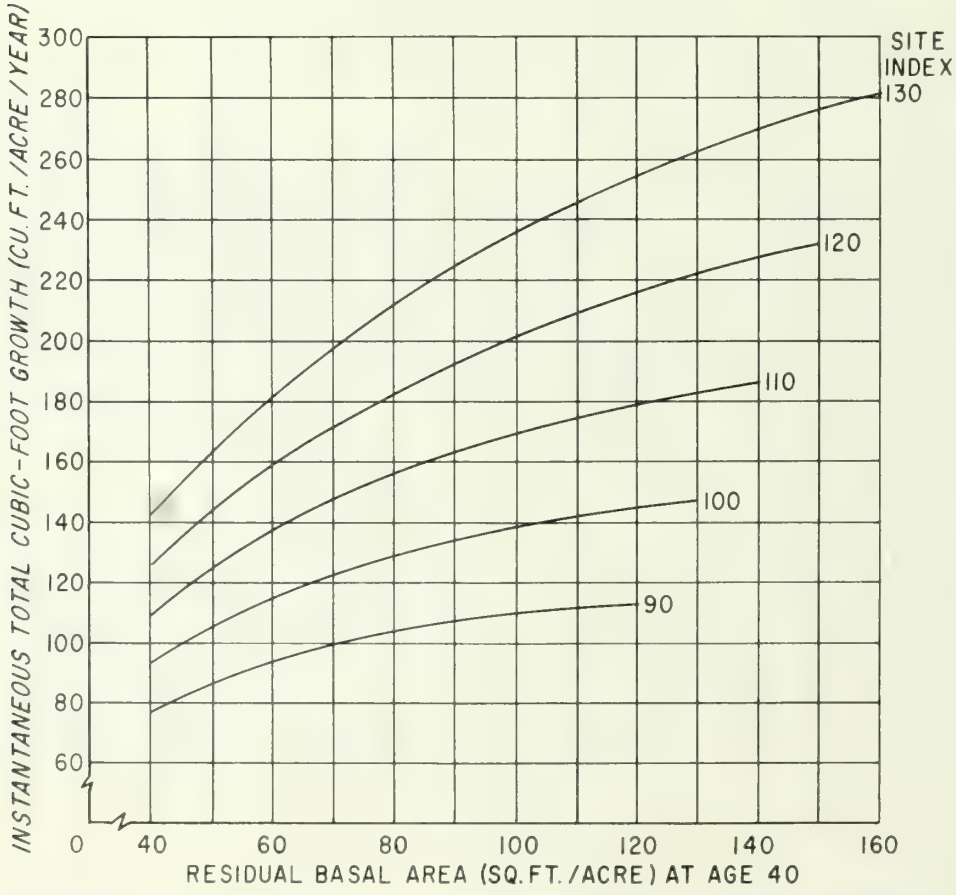

Figure 3.--Instantaneous total cubic-foot growth in relation to site index and residual basal area at age 40.

reached at approximately 80 square feet of basal area per acre. But on site index 130 in a 40-year-old stand, the rate of basal-area growth is still increasing at 160 square feet of basal area per acre, indicating that high residual densities are justifiable for our best yellow-poplar sites.

Probably the most instructive comparisons can be made by using equation (6) for projected total cubic-foot yield and equation (8) for projected basal area. By evaluating these equations with different values for the independent variables, the results by varying density, rotation age, and thinning regime can be examined. Figures 8 and 9, for example, are graphic presentations of solutions of the projecting equations for several initial densities and site-index values at age 20.

Consider, for example, a previously unthinned stand of 40-year-old yellow-poplar at site index 110 and with 150 square feet of basal area per acre. To concentrate growth on the best trees, the stand must be thinned. What thinning regime should be followed? Figures 4 through 7 illustrate basal-area and cubic-foot yield under two of many alternative schemes. Under option A (figures 4 and 5), the stand is thinned to 120 square feet of basal area per acre and carried to rotation age 70 without further thinning. Under option B (figures 6 and 7), the 40-year-old stand is thinned to 120 square feet of basal area per acre, is rethinned to the same level at age 50 and again at age 60, and liquidated at age 70.

In order to graphically project total cubic-foot yield it is necessary to first project basal area. For example, to determine production under option A, enter figure 4 at age 40 and 150 square feet of basal area. This point lies approximately on the curve of expected development for a stand that began with 80 square feet of basal area at age 20. When the stand is thinned to 120 square feet per acre it drops down to the curve for a stand with a basal area at age 20 of 50 square feet per acre and develops along this curve to age 70. In figure 5, enter at age 40 and go up to the curve for basal area 80 at age 20. Estimated total cubic-foot yield of the stand is read off the left. Dropping down to the curve for basal area 50 at age 20 gives total cubic-foot yield of the stand at age 40 after thinning. Projecting the stand along the curve for basal area 50 at age 20 gives total cubic-foot yield at age 70 under option A.

Basal-area and total cubic-foot yield under options A and B are summarized in table 4. In total cubic-foot yield there is no measurable difference between the two thinning options. On the other hand, tree-size distribution and possibly merchantable yields would differ, permitting a choice of thinning regimes based on these factors.

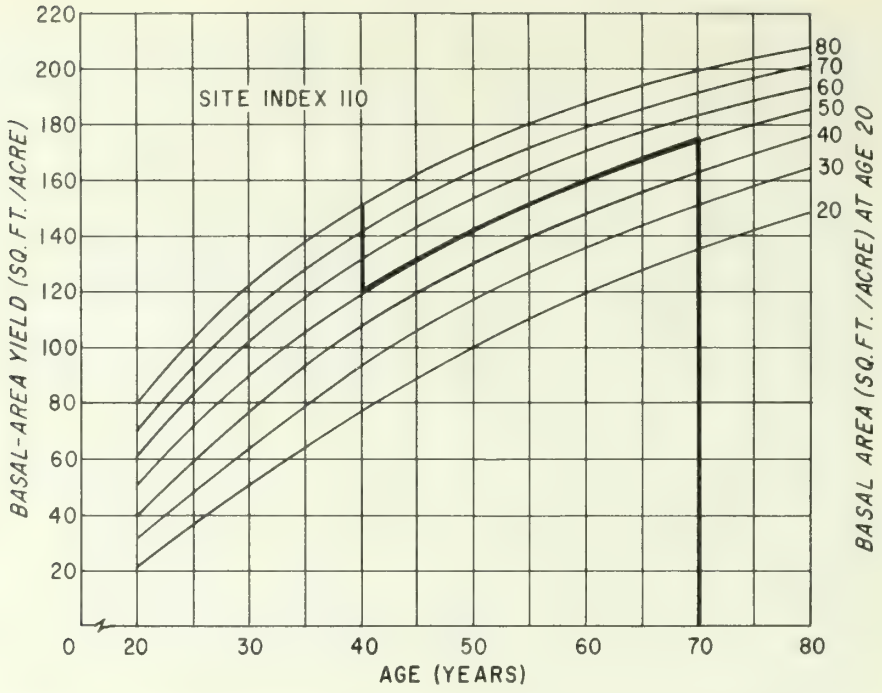

Figure 4.--Predicted basal-area yield for yellow-poplar stand of site index 110 with basal area of 150 square feet at age 40 under option A.

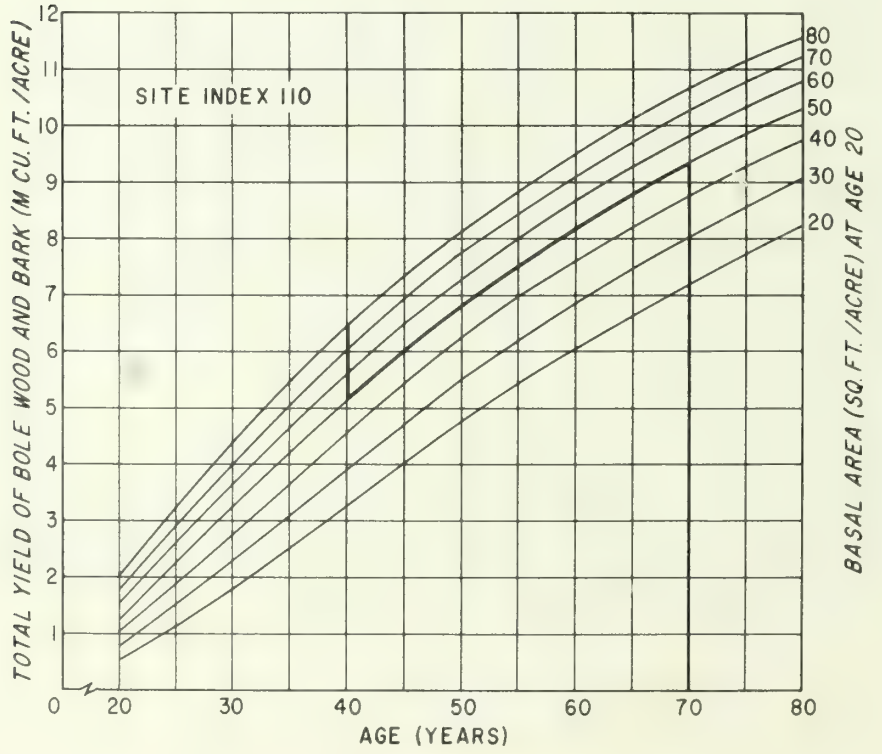

Figure 5.--Predicted total cubic-foot yield for yellow-poplar stand of site index 110 with basal area of 150 square feet at age 40 under option A.

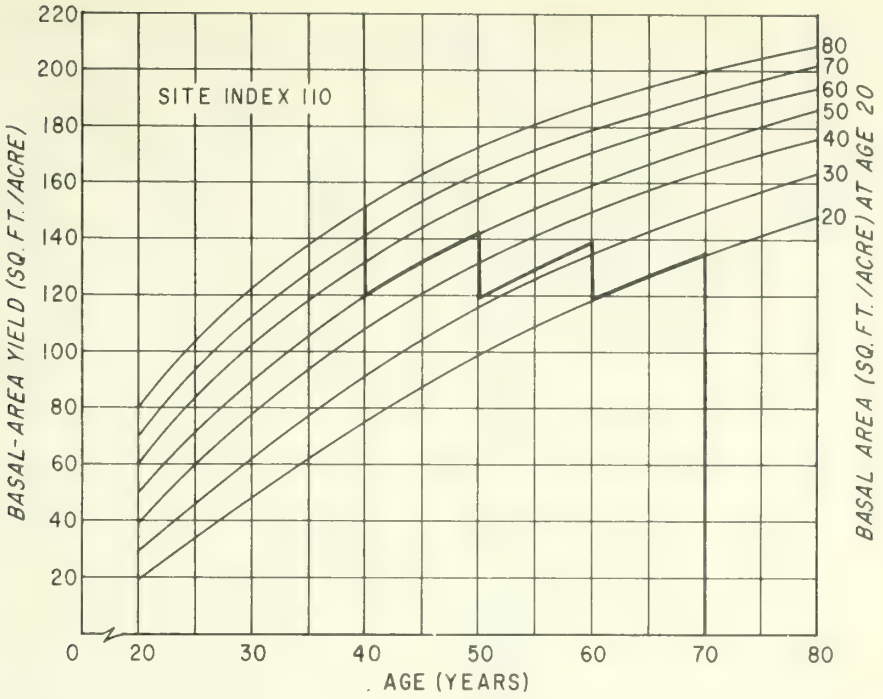

Figure 6.--Predicted basal-area yield for yellow-poplar stand of site index 110 with basal area of 150 square feet at age 40 under option B.

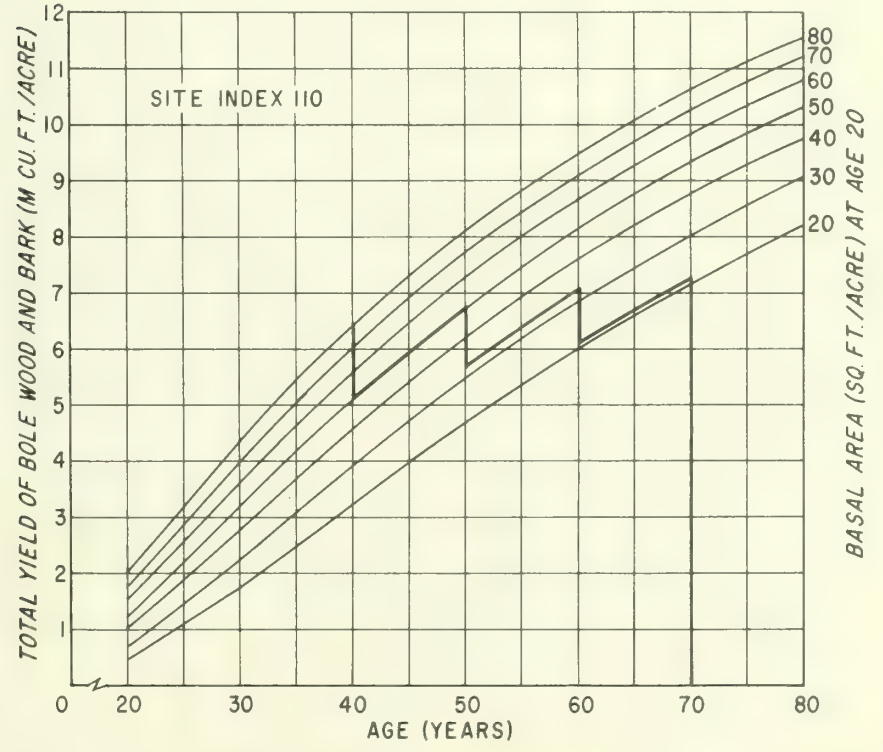

Figure 7.--Predicted total cubic-foot yield for yellow-poplar stand of site index 110 with basal area of 150 square feet at age 40 under option B.

Table 4.--Yield for a yellow-poplar stand with site index 110, age 40, with 150 square feet of basal area per acre, under two thinning options

OPTION A

Age (years)	Basal area			Total cubic-foot volume		
	Before thinning	After thinning	Amount cut	Before thinning	After thinning	Amount cut
	Sq. ft./acre			Cu. ft./acre		
40	150	120	30	6,379	5,149	1,230
70	174	0	174	9,350	0	9,350
Total			204			10,580

OPTION B

40	150	120	30	6,379	5,149	1,230
50	143	120	23	6,795	5,734	1,061
60	139	120	19	7,108	6,170	938
70	136	0	136	7,345	0	7,345
Total			208			10,574

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APPENDIX

Table 5. --Total cubic-foot yield for thinned stands of yellow-poplar[1]

SITE INDEX 90

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cu. ft./acre												
20	831	1,032	1,232	1,431									
25	1,036	1,286	1,536	1,783	2,030								
30	1,199	1,490	1,778	2,065	2,351	2,636	2,920						
35	1,332	1,654	1,974	2,293	2,611	2,927	3,242	3,557					
40	1,441	1,789	2,136	2,481	2,824	3,166	3,508	3,848	4,187				
45	1,531	1,902	2,270	2,637	3,002	3,366	3,729	4,090	4,451				
50	1,608	1,997	2,384	2,769	3,153	3,535	3,915	4,295	4,674	5,052			
55	1,674	2,079	2,481	2,882	3,281	3,679	4,075	4,470	4,865	5,258			
60	1,731	2,149	2,566	2,980	3,393	3,804	4,213	4,622	5,030	5,436	5,842		
65	1,780	2,211	2,639	3,065	3,490	3,912	4,334	4,754	5,173	5,592	6,009		
70	1,824	2,265	2,704	3,140	3,575	4,008	4,440	4,870	5,300	5,728	6,156	6,582	
75	1,862	2,313	2,761	3,207	3,651	4,093	4,534	4,974	5,412	5,850	6,286	6,722	
80	1,897	2,356	2,812	3,266	3,718	4,169	4,618	5,066	5,512	5,958	6,403	6,846	7,289

SITE INDEX 100

20	930	1,155	1,379	1,602	1,823								
25	1,159	1,439	1,718	1,996	2,272	2,547							
30	1,342	1,667	1,990	2,311	2,631	2,950	3,267	3,584					
35	1,490	1,851	2,209	2,566	2,921	3,275	3,628	3,980	4,331				
40	1,612	2,002	2,390	2,776	3,160	3,543	3,925	4,306	4,685	5,064	5,442		
45	1,714	2,128	2,541	2,951	3,359	3,766	4,172	4,577	4,980	5,383	5,785		
50	1,799	2,235	2,668	3,099	3,528	3,955	4,381	4,806	5,230	5,653	6,074	6,496	6,916
55	1,873	2,326	2,777	3,225	3,672	4,116	4,560	5,002	5,443	5,883	6,322	6,760	7,198
60	1,936	2,405	2,871	3,334	3,796	4,256	4,715	5,172	5,628	6,083	6,537	6,990	7,442
65	1,992	2,474	2,953	3,430	3,905	4,378	4,850	5,320	5,789	6,257	6,724	7,190	7,655
70	2,040	2,534	3,025	3,514	4,000	4,485	4,968	5,450	5,930	6,410	6,888	7,366	7,842
75	2,084	2,588	3,089	3,588	4,085	4,580	5,073	5,565	6,056	6,546	7,034	7,522	8,008
80	2,122	2,636	3,146	3,655	4,160	4,665	5,167	5,668	6,168	6,667	7,164	7,661	8,156

SITE INDEX 110

20	1,020	1,266	1,512	1,756	1,999								
25	1,270	1,578	1,884	2,188	2,491	2,793	3,094	3,394					
30	1,471	1,827	2,181	2,533	2,884	3,234	3,582	3,930	4,276	4,622			
35	1,634	2,029	2,422	2,813	3,203	3,591	3,978	4,364	4,748	5,132			
40	1,767	2,195	2,620	3,043	3,465	3,884	4,303	4,720	5,136	5,552	5,965	6,379	
45	1,879	2,333	2,785	3,235	3,683	4,129	4,574	5,018	5,460	5,902	6,342	6,781	7,220
50	1,973	2,450	2,925	3,397	3,867	4,336	4,803	5,269	5,734	6,197	6,660	7,121	7,582
55	2,053	2,550	3,044	3,536	4,025	4,513	4,999	5,484	5,968	6,450	6,931	7,412	7,891
60	2,123	2,637	3,147	3,656	4,162	4,666	5,169	5,670	6,170	6,669	7,166	7,663	8,159
65	2,184	2,712	3,237	3,760	4,281	4,800	5,317	5,832	6,346	6,860	7,371	7,882	8,392
70	2,237	2,778	3,316	3,852	4,386	4,917	5,447	5,975	6,502	7,027	7,552	8,075	8,597
75	2,284	2,837	3,387	3,934	4,478	5,021	5,562	6,102	6,640	7,176	7,712	8,246	8,780
80	2,327	2,890	3,449	4,006	4,561	5,114	5,665	6,214	6,762	7,309	7,854	8,399	8,942

SITE INDEX 120

20	1,101	1,367	1,632	1,896	2,158	2,420							
25	1,372	1,704	2,034	2,362	2,689	3,015	3,340	3,664	3,987				
30	1,588	1,973	2,355	2,735	3,114	3,491	3,868	4,242	4,617	4,990	5,362		
35	1,764	2,191	2,615	3,037	3,458	3,877	4,295	4,711	5,126	5,541	5,954	6,367	6,779
40	1,908	2,370	2,829	3,286	3,740	4,194	4,646	5,096	5,546	5,994	6,441	6,888	7,333
45	2,028	2,519	3,007	3,493	3,976	4,458	4,938	5,417	5,895	6,372	6,847	7,322	7,795
50	2,130	2,645	3,158	3,668	4,176	4,682	5,186	5,689	6,190	6,691	7,190	7,688	8,186
55	2,217	2,753	3,287	3,817	4,346	4,872	5,398	5,921	6,443	6,964	7,484	8,002	8,520
60	2,292	2,847	3,398	3,947	4,493	5,038	5,580	6,122	6,661	7,200	7,737	8,273	8,808
65	2,358	2,928	3,495	4,060	4,622	5,182	5,740	6,297	6,852	7,406	7,959	8,510	9,060
70	2,415	3,000	3,581	4,159	4,735	5,309	5,881	6,451	7,020	7,587	8,153	8,718	9,282
75	2,466	3,063	3,656	4,247	4,835	5,421	6,005	6,588	7,168	7,748	8,326	8,903	9,479
80	2,512	3,120	3,724	4,326	4,924	5,521	6,116	6,709	7,301	7,891	8,480	9,068	9,654

[1]Only bole wood and bark of trees 4.5 inches d.b.h. and larger are included.

Table 5.--Total cubic-foot yield for thinned stands of yellow-poplar[1] (continued)

SITE INDEX 130

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cu. ft./acre												
20	1,175	1,459	1,741	2,023	2,303	2,582	2,860						
25	1,464	1,818	2,170	2,520	2,869	3,217	3,564	3,909	4,254	4,598			
30	1,695	2,105	2,513	2,918	3,323	3,725	4,127	4,527	4,926	5,324	5,721	6,118	6,514
35	1,882	2,337	2,790	3,241	3,690	4,137	4,582	5,027	5,470	5,912	6,353	6,794	7,233
40	2,036	2,529	3,018	3,506	3,991	4,475	4,957	5,438	5,917	6,395	6,873	7,349	7,824
45	2,164	2,688	3,208	3,727	4,243	4,757	5,269	5,780	6,290	6,798	7,306	7,812	8,317
50	2,273	2,822	3,369	3,913	4,455	4,995	5,533	6,070	6,605	7,139	7,672	8,204	8,734
55	2,365	2,938	3,507	4,073	4,637	5,199	5,759	6,318	6,875	7,430	7,985	8,538	9,090
60	2,446	3,037	3,626	4,211	4,794	5,375	5,954	6,532	7,108	7,682	8,256	8,828	9,399
65	2,516	3,124	3,729	4,332	4,931	5,529	6,125	6,719	7,311	7,902	8,492	9,080	9,668
70	2,577	3,201	3,821	4,438	5,052	5,664	6,274	6,883	7,490	8,095	8,700	9,302	9,904
75	2,632	3,268	3,902	4,532	5,159	5,784	6,407	7,029	7,649	8,267	8,884	9,499	10,114
80	2,680	3,329	3,974	4,615	5,254	5,891	6,526	7,159	7,790	8,420	9,048	9,675	10,301

[1]Only bole wood and bark of trees 4.5 inches d.b.h. and larger are included.

Table 6.--Instantaneous basal-area growth for thinned stands of yellow-poplar[1 2]

SITE INDEX 90

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Sq. ft./acre/year												
20	3.3	3.5	3.7	3.8									
25	2.6	2.8	3.0	3.0	3.0								
30	2.2	2.4	2.5	2.5	2.5	2.5	2.4						
35	1.9	2.0	2.1	2.2	2.2	2.1	2.1	2.0					
40	1.6	1.8	1.9	1.9	1.9	1.9	1.8	1.7	1.6				
45	1.5	1.6	1.6	1.7	1.7	1.7	1.6	1.5	1.4				
50	1.3	1.4	1.5	1.5	1.5	1.5	1.4	1.4	1.3	1.2			
55	1.2	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.2	1.1			
60	1.1	1.2	1.2	1.3	1.3	1.2	1.2	1.2	1.1	1.0	0.9		
65	1.0	1.1	1.1	1.2	1.2	1.1	1.1	1.1	1.0	0.9	0.8		
70	0.9	1.0	1.1	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.7	
75	0.9	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.8	0.7	0.6	
80	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.7	0.7	0.6	0.5
	SITE INDEX 100												
20	3.6	4.0	4.2	4.4	4.5								
25	2.9	3.2	3.4	3.5	3.6	3.6							
30	2.4	2.6	2.8	2.9	3.0	3.0	3.0	2.9					
35	2.1	2.3	2.4	2.5	2.5	2.6	2.5	2.5	2.4				
40	1.8	2.0	2.1	2.2	2.2	2.2	2.2	2.2	2.1	2.0	1.9		
45	1.6	1.8	1.9	1.9	2.0	2.0	2.0	1.9	1.9	1.8	1.7		
50	1.4	1.6	1.7	1.7	1.8	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.3
55	1.3	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.4	1.3	1.2
60	1.2	1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.3	1.2	1.1
65	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.1	1.0
70	1.0	1.1	1.2	1.2	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.0	1.0
75	1.0	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.0	1.0	0.9
80	0.9	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	0.9	0.8

[1]Only trees 4.5 inches d.b.h. and larger are included.
[2]First derivative of equation (8), equation (9).

Table 6.--Instantaneous basal-area growth for thinned stands of yellow-poplar[1] [2] (continued)

SITE INDEX 110

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Sq. ft./acre/year												
20	3.9	4.4	4.7	4.9	5.1								
25	3.2	3.5	3.8	4.0	4.1	4.2	4.2	4.2					
30	2.6	2.9	3.1	3.3	3.4	3.5	3.5	3.5	3.5	3.4			
35	2.3	2.5	2.7	2.8	2.9	3.0	3.0	3.0	3.0	3.0			
40	2.0	2.2	2.4	2.5	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.4	
45	1.8	1.9	2.1	2.2	2.3	2.3	2.3	2.4	2.3	2.3	2.2	2.2	2.1
50	1.6	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.0	2.0	1.9
55	1.4	1.6	1.7	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.7
60	1.3	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.7	1.7	1.7	1.6	1.6
65	1.2	1.3	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.4
70	1.1	1.3	1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.3
75	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3
80	1.0	1.1	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2

SITE INDEX 120

20	4.3	4.8	5.2	5.5	5.8	6.0							
25	3.4	3.8	4.2	4.4	4.6	4.8	4.9	5.0	5.0				
30	2.9	3.2	3.5	3.7	3.9	4.0	4.1	4.1	4.2	4.2	4.1		
35	2.4	2.7	3.0	3.2	3.3	3.4	3.5	3.5	3.6	3.6	3.5	3.5	3.4
40	2.1	2.4	2.6	2.8	2.9	3.0	3.1	3.1	3.1	3.1	3.1	3.1	3.0
45	1.9	2.1	2.3	2.5	2.6	2.7	2.7	2.8	2.8	2.8	2.8	2.7	2.7
50	1.7	1.9	2.1	2.2	2.3	2.4	2.4	2.5	2.5	2.5	2.5	2.5	2.4
55	1.6	1.7	1.9	2.0	2.1	2.2	2.2	2.3	2.3	2.3	2.3	2.2	2.2
60	1.4	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.1	2.0	2.0
65	1.3	1.5	1.6	1.7	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9
70	1.2	1.4	1.5	1.6	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.7
75	1.1	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.7	1.6	1.6
80	1.1	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5

SITE INDEX 130

20	4.6	5.2	5.7	6.1	6.5	6.7	7.0						
25	3.7	4.2	4.6	4.9	5.2	5.4	5.6	5.7	5.8	5.9			
30	3.1	3.5	3.8	4.1	4.3	4.5	4.6	4.7	4.8	4.9	4.9	4.9	4.9
35	2.6	3.0	3.3	3.5	3.7	3.8	4.0	4.1	4.1	4.2	4.2	4.2	4.2
40	2.3	2.6	2.9	3.1	3.2	3.4	3.5	3.6	3.6	3.7	3.7	3.7	3.7
45	2.1	2.3	2.5	2.7	2.9	3.0	3.1	3.2	3.2	3.3	3.3	3.3	3.3
50	1.8	2.1	2.3	2.4	2.6	2.7	2.8	2.8	2.9	2.9	3.0	3.0	2.9
55	1.7	1.9	2.1	2.2	2.3	2.4	2.5	2.6	2.6	2.7	2.7	2.7	2.7
60	1.5	1.7	1.9	2.0	2.2	2.2	2.3	2.4	2.4	2.4	2.5	2.5	2.5
65	1.4	1.6	1.8	1.9	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.3	2.3
70	1.3	1.5	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.1	2.1
75	1.2	1.4	1.5	1.6	1.7	1.8	1.9	1.9	1.9	2.0	2.0	2.0	2.0
80	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8

[1] Only trees 4.5 inches d.b.h. and larger are included.
[2] First derivative of equation (8), equation (9).

Table 7.--Instantaneous total cubic-foot growth for thinned stands of yellow-poplar[1] [2]

SITE INDEX 90

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cu. ft./acre/year												
20	112	128	142	154									
25	102	116	128	138	146								
30	93	105	114	123	130	135	140						
35	84	95	103	110	116	120	123	126					
40	77	86	93	99	104	107	110	112	113				
45	71	79	85	90	94	97	99	100	100				
50	65	72	78	82	86	88	90	90	90	90			
55	61	67	72	76	79	81	82	82	82	81			
60	56	62	67	70	73	74	75	75	75	74	72		
65	53	58	62	65	68	69	69	69	69	68	66		
70	50	55	58	61	63	64	64	64	64	62	61	59	
75	47	52	55	57	59	60	60	60	59	58	56	54	
80	44	49	52	54	56	56	56	56	55	54	52	50	48

SITE INDEX 100

20	133	152	170	185	199								
25	122	139	154	167	178	188							
30	111	126	139	150	159	167	174	180					
35	102	115	126	135	143	149	155	159	163				
40	93	104	114	122	129	134	139	142	145	147	148		
45	85	96	104	112	117	122	126	128	130	131	132		
50	79	88	96	102	107	111	114	116	118	119	119	118	117
55	73	82	89	94	99	102	105	107	108	108	108	107	106
60	68	76	83	88	92	95	97	98	99	99	98	98	96
65	64	71	77	82	85	88	90	91	91	91	91	90	88
70	60	67	72	77	80	82	84	85	85	85	84	83	81
75	57	63	68	72	75	77	78	79	79	79	78	77	75
80	54	60	64	68	70	72	74	74	74	74	73	71	70

SITE INDEX 110

20	154	177	198	217	234								
25	142	163	181	197	212	224	236	246					
30	130	148	164	178	190	201	210	218	226	232			
35	119	135	149	161	171	180	188	195	200	205			
40	109	123	136	146	155	163	170	175	180	183	186	189	
45	100	114	124	134	142	148	154	159	162	165	168	169	170
50	93	105	115	123	130	136	141	145	148	150	152	153	153
55	86	97	106	114	120	125	130	133	136	137	139	139	139
60	81	91	99	106	112	116	120	123	125	126	127	128	127
65	76	85	93	99	104	108	112	114	116	117	118	118	117
70	71	80	87	93	98	101	104	106	108	109	109	109	109
75	67	75	82	87	92	95	98	100	101	102	102	102	101
80	64	71	78	82	87	90	92	94	95	96	96	95	94

[1] Only bole wood and bark of trees 4.5 inches d.b.h. and larger are included.
[2] First derivative of equation (7), equation (10).

Table 7.--Instantaneous total cubic-foot growth for thinned stands of yellow-poplar[1] [2] (continued)

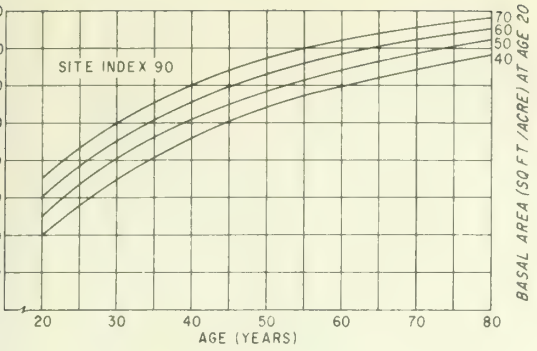
SITE INDEX 120

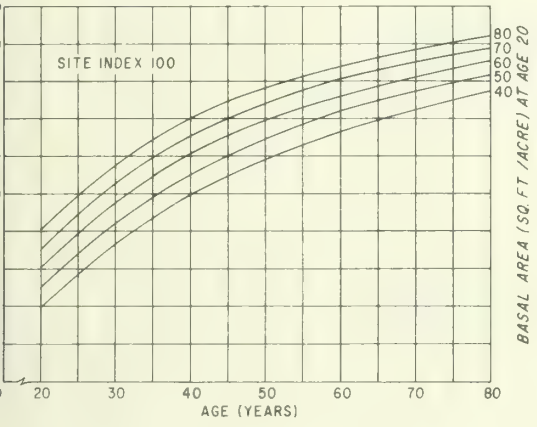
Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cu. ft./acre/year												
20	174	202	227	250	270	289							
25	162	187	209	228	246	262	276	290	302				
30	149	171	190	207	222	236	248	259	268	277	285		
35	136	156	173	188	201	213	223	232	240	247	254	259	264
40	125	143	158	171	183	193	202	210	216	222	227	232	235
45	116	132	145	157	167	176	184	191	196	201	206	209	212
50	107	122	134	145	154	162	169	175	180	184	187	190	192
55	100	113	125	134	143	150	156	161	165	169	172	174	175
60	93	106	116	125	133	139	145	149	153	156	158	160	161
65	88	99	109	117	124	130	135	139	142	145	147	148	149
70	83	93	102	110	116	122	126	130	133	135	137	138	139
75	78	88	96	104	110	114	119	122	125	127	128	129	130
80	74	83	91	98	103	108	112	115	117	119	120	121	122

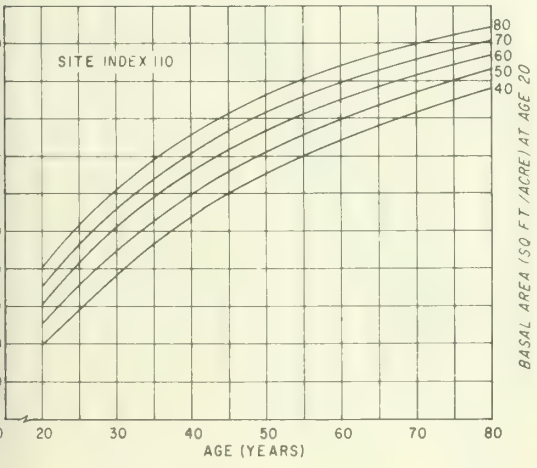
SITE INDEX 130

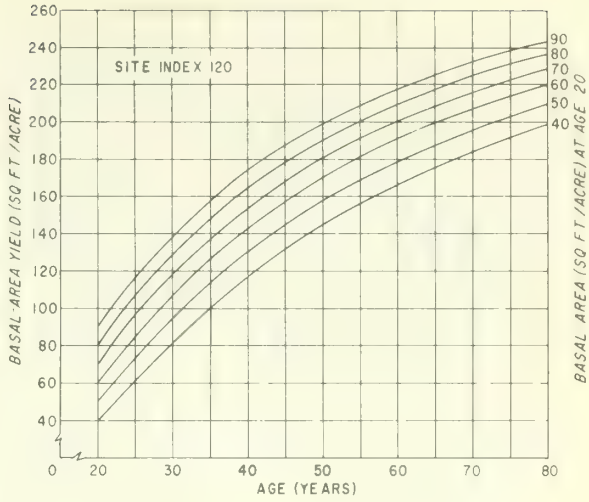
20	196	228	256	283	307	330	350						
25	183	211	237	260	281	300	318	334	349	363			
30	168	193	216	236	255	271	287	300	313	325	335	345	353
35	154	177	197	215	231	246	259	271	282	291	300	308	315
40	142	163	181	197	211	224	236	246	255	263	270	277	282
45	131	150	166	181	194	205	215	224	232	239	246	251	256
50	122	139	154	167	179	189	198	206	213	219	225	229	233
55	114	129	143	155	166	175	183	190	197	202	207	211	214
60	106	121	134	145	154	163	170	177	182	187	191	195	198
65	100	114	125	136	145	152	159	165	170	174	178	181	183
70	94	107	118	128	136	143	149	155	159	163	166	169	171
75	89	101	111	120	128	135	140	145	150	153	156	158	160
80	84	96	105	114	121	127	133	137	141	144	147	149	150

[1] Only bole wood and bark of trees 4.5 inches d.b.h. and larger are included.
[2] First derivative of equation (7), equation (10).









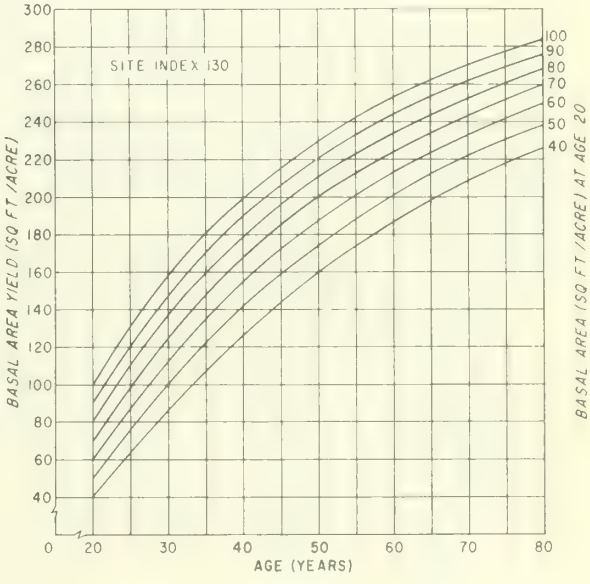
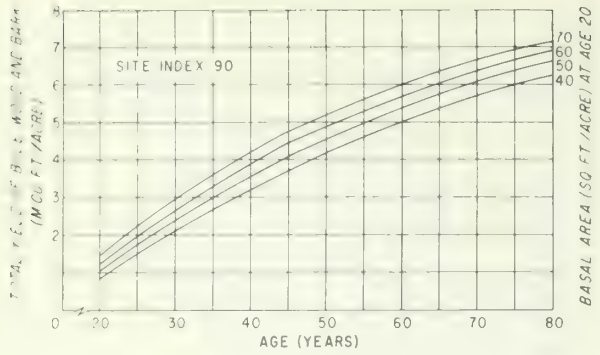
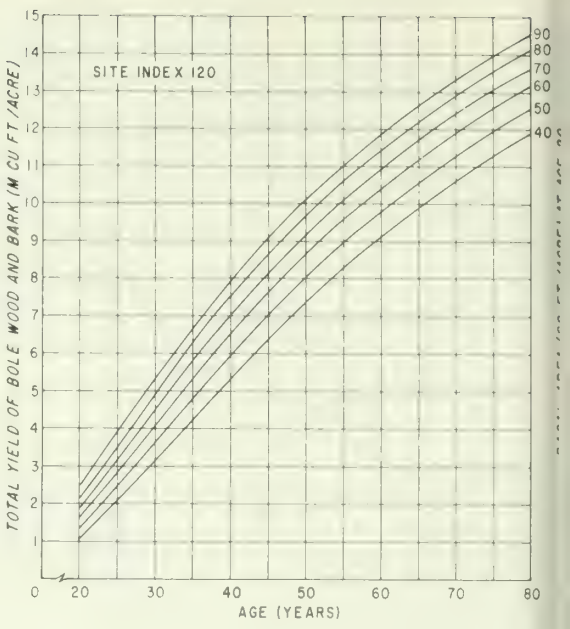
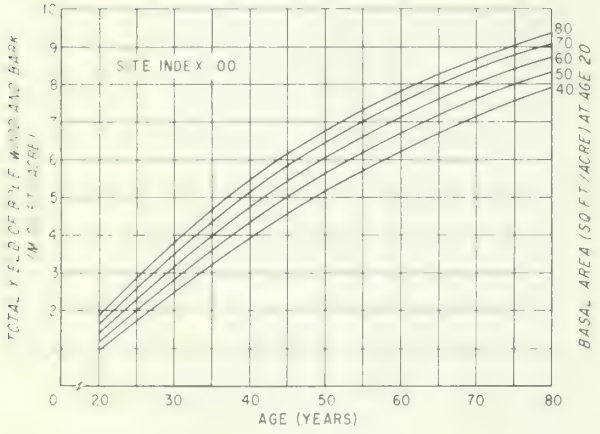
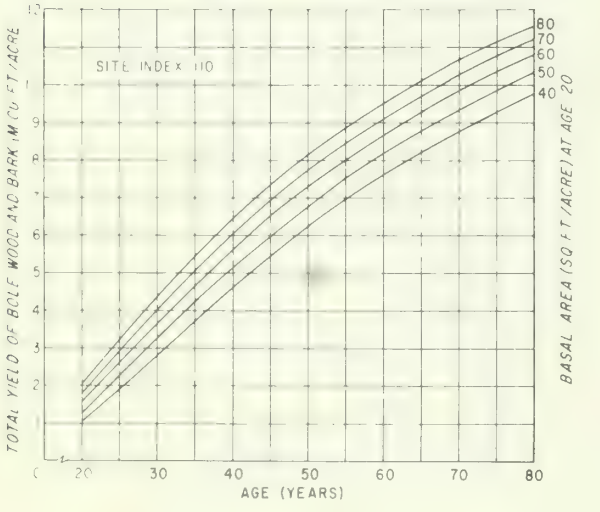


Figure 8.--Projected basal-area yield by site index, age, and basal area at age 20.









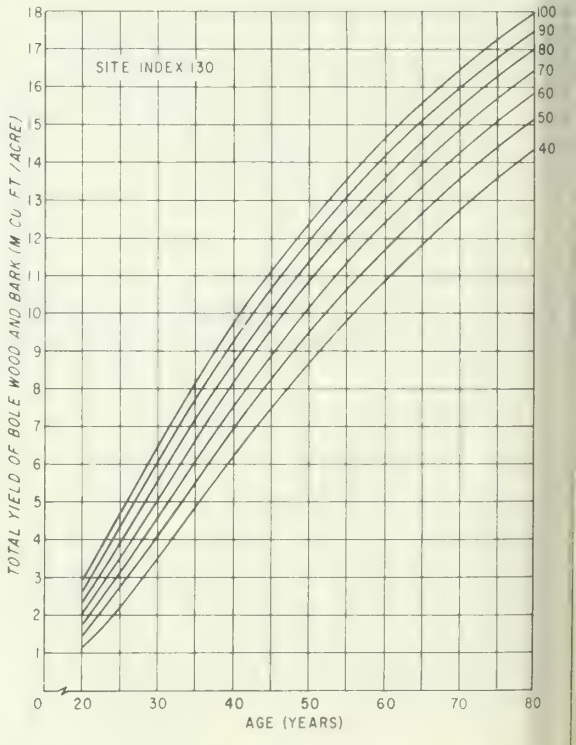


Figure 9.--Projected total cubic-foot yield by site index, age, and basal area at age 20.

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Beck, Donald E., and Della-Bianca, Lino
1972. Growth and yield of thinned yellow-poplar. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-101, 20 pp.

Basal area and cubic-foot volume development of stands of yellow-poplar (Liriodendron tulipifera L.) is described in relation to age, site index, and stand density following thinning. The growth and yield equations and tables are based on data from 141 natural yellow-poplar stands in the Appalachian Mountains of Virginia, North Carolina, and Georgia.

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SDA Forest Service Research Paper SE-102 December 1972

A New Nail to Eliminate Nail Popping and Dimpling under Resilient Tile Flooring

by
Charles B. Vick
and
Roy M. Walker

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Charles B. Vick, Wood Scientist

and

Roy M. Walker, Research Technician

Forestry Sciences Laboratory
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INTRODUCTION

Nail popping is a term commonly used to describe protrusion of a nailhead above the plane of a normally smooth surface. Conversely, dimpling is an indentation of a smooth surface by a nailhead that is recessed below the surface plane. Both occur in wood-based floors, usually as a consequence of the shrinking and swelling of the wood. Nail popping and dimpling are frequent problems in flooring of smooth-surfaced resilient tiles because even a slight protrusion or indentation (0.005 inch or more) of a nailhead beneath thin tile is easily visible in reflected light across the upper surface (figures 1 and 2). Although these defects usually are not indicative of structural weakness, they are unsightly and costly to repair. Such nuisances tend to force homeowners, builders, and architects to seek other finish flooring and base materials that will give more satisfactory service.

Vast improvements have been made in the design of nails within recent years, with the result that nail popping in thin tile flooring can be significantly reduced by proper installation. Because nail popping is associated with deep penetration of long nails into shrinking floor joists, the use of shorter, higher strength nails can reduce this problem without loss in holding ability (4). In addition, grooved and threaded nail shanks have resulted in considerable increases in, as well as retention of, withdrawal resistance in comparison with that of conventional smooth-shanked nails.

Annular-grooved nails are probably the most effective commercial nails for fastening underlayment because of their great withdrawal resistance. However, even they do not eliminate nail popping altogether.

Figure 1.--Nail popping along a floor joist in a plywood-based floor system under thin resilient tile.

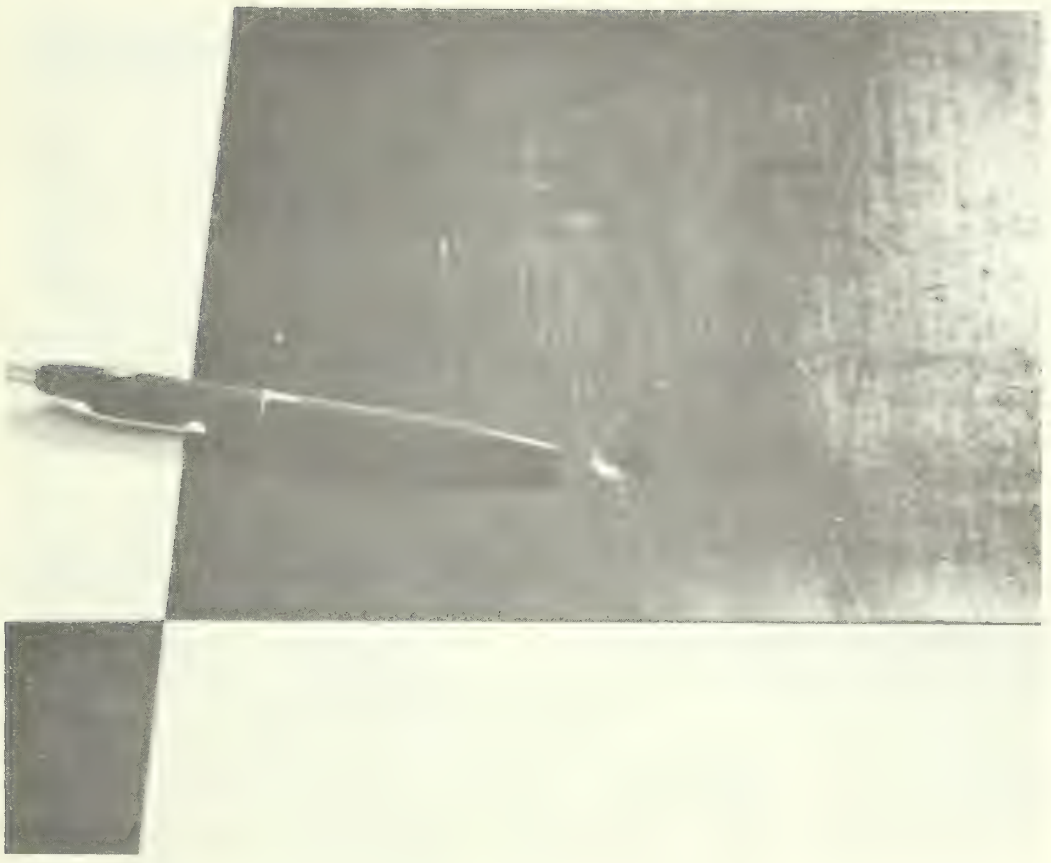

Figure 2.--A dimple in thin resilient tile at the head of a recessed underlayment nail. Such dimples may be caused by changes in the thickness of plywood underlayment during seasonal changes in moisture content.

Studies by Stern (5), Suddarth and Angleton (6), and Luxford (2) have shown that nails are subject to popping whenever wood shrinks after nailing, regardless of how great the withdrawal resistances may be. Suddarth and Angleton concluded that the amount of nail popping is directly and proportionally related to the amount of wood shrinkage but that nail length or depth of penetration exerts the greatest influence on the amount of popping. They further concluded that the upper limits of the maximum popping in a given situation are the shrinkage which occurs over the depth of penetration of an embedded nail or that which occurs over half the depth of a board completely penetrated by a nail.

There is no clear agreement between these various investigators regarding the influence of withdrawal resistance of a nail on the amount of cumulative creep that may take place during cyclic changes in moisture content of the wood. (Cumulative creep refers here to successive increases in the outward popping or emergence of a nail.) Stern (5) has shown that smooth-shanked nails, both cement-coated and uncoated, are subject to cumulative creep under such cyclic changes whereas annular-

grooved nails are not. The limited study by Suddarth and Angleton (6) indicated that both annular-grooved and smooth-shanked nails undergo cumulative creep under severe conditions of cyclic exposure to moisture.

In a recent study involving five types of short fasteners including screws and annular-grooved and smooth-shanked nails, each differing in withdrawal resistance, Vick (7) showed that none were subject to cumulative outward creep during cyclic changes in moisture content. Creep was prevented by driving the points of these fasteners through the plywood underlayment and subflooring but not allowing them to penetrate floor joists or other solid members. The study also illustrated that nail popping can be significantly reduced by this arrangement but not completely eliminated because of shrinkage of the plywood.

OBJECTIVES

Because none of the conventional fasteners and fastening techniques were found to eliminate popping and dimpling completely, a special underlayment nail was designed to eliminate these problems in plywood-based flooring regardless of the amounts of shrinking and swelling involved. This nail was then subjected to a series of performance tests. The design and performance of the new nail are reported here.

It should be recognized that the nail described is a prototype that was handmade in the laboratory in limited number. Consequently, as will be pointed out later, certain minor changes in design may become necessary to improve its performance and to allow for the dimensional tolerances of which mass-production machinery is capable. Although the results of the four tests presented here must therefore be considered as preliminary findings only, they should serve as an adequate illustration of the nail's performance.

DESIGN OF THE NEW NAIL

The configuration and dimensions of the underlayment nail are shown in figure 3. Overall length of the nail is 1.250 inches. At the upper end of the shank, a driving head measuring 0.100 inch in diameter projects 0.045 inch above the first annular groove. The upper nail shank, which is larger in diameter than the lower shank, consists of nine annular grooves spaced 0.060 inch apart. Diameters measure 0.100 inch at the base of each groove and 0.150 inch at the crown (Section A–A′). The lower nail shank has 15 annular grooves, with the uppermost groove of the lower shank merging with the lowermost groove of the upper shank. The smaller grooves are spaced 0.036 inch apart. They have a base diameter of 0.070 inch and a crown diameter of 0.100 inch (Section B–B′). The needle point at the lower end of the shank is 0.125 inch long and converges to a point from a 0.100-inch diameter.

This nail was designed to fasten underlayment and subflooring of specific thicknesses typical of residential construction in the Southeast. When builders in this region wish to install thin resilient tile adjacent to

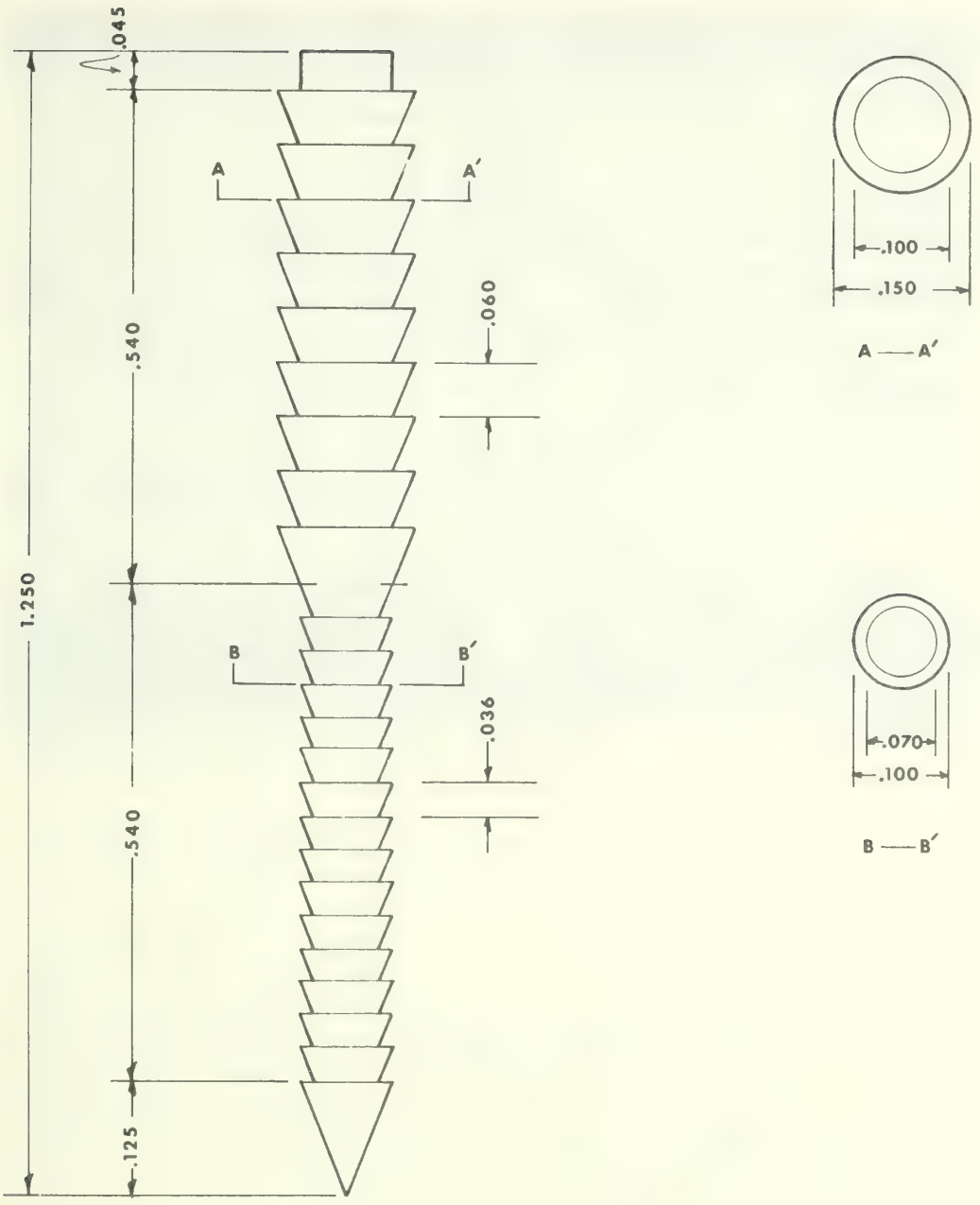

Figure 3. --Configuration and dimensions of the new underlayment nail.

25/32-inch-thick strip flooring (usually hardwood flooring), the common practice is to use 1/2-inch-thick plywood subflooring throughout the house and to build up the tile floor with 5/8-inch-thick plywood underlayment to the finished level of the strip flooring. Thus, the nail shown in figure 3 is the proper size for fastening underlayment and subflooring of these thicknesses. As shown in figure 4, the nail is so proportioned that, when driven, the upper shank with its larger diameter is embedded only in the underlayment and the lower shank is embedded only in the subflooring. The nail has sufficient length to allow the nail point to project

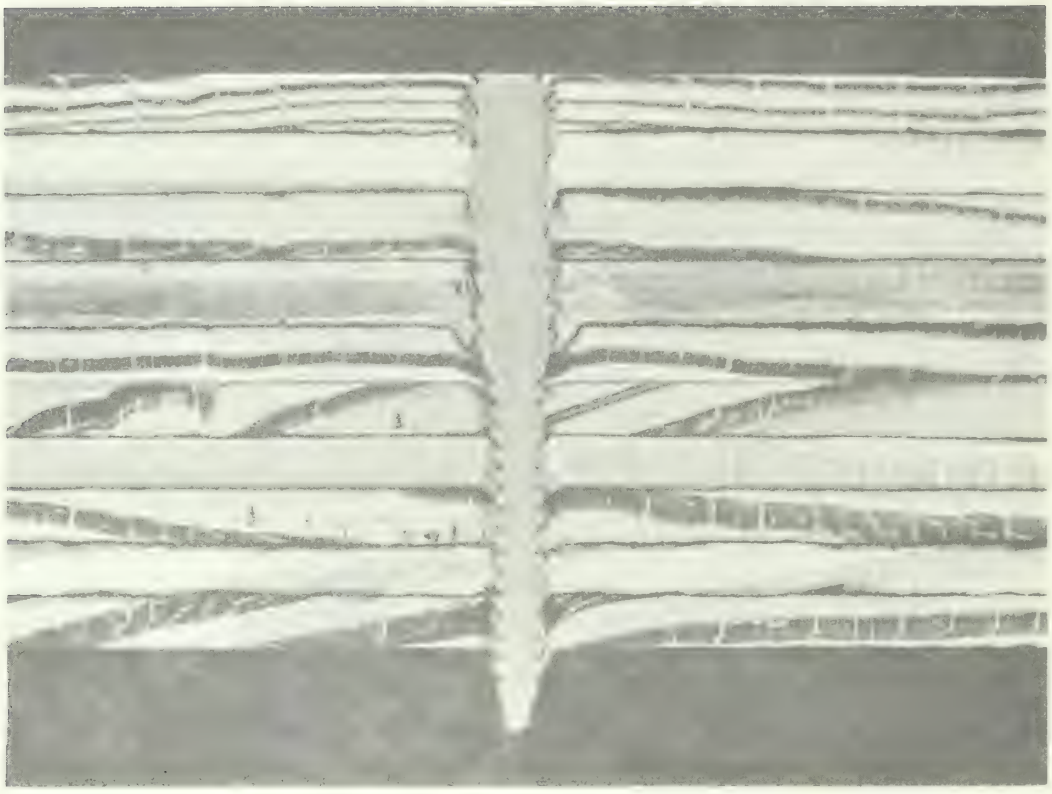

Figure 4.--A cross-sectional view of the new underlayment nail as it is normally positioned in 5/8-inch-thick underlayment and 1/2-inch-thick subflooring. (The point of separation between underlayment and subflooring lies between the 5th and 6th layers of veneer.)

approximately 1/8 inch from the undersurface of the subflooring. However, the lower shank could be lengthened to extend through 5/8-inch-thick plywood subflooring or 3/4-inch-thick lumber subflooring. In any case, it is important that the nail point be free of any obstructions, such as joists or blocking, as it emerges from the subflooring. Otherwise, the nail could be forced to back out if repeated loading of the floor caused the point to bear on an obstruction.

The new nail does not have a conventional type of head. Instead, the head is essentially the upper shank, which is completely embedded in the underlayment. Thus, there is no large head to mar the smooth surface of the tile with dimples and nail pops when shrinkage or swelling occurs in the wood. Furthermore, indentations that often occur when the large, flat heads of conventional nails are driven beneath the surface plane are eliminated altogether. If shrinkage should be expected after nailing, the head of the new nail can be countersunk to a depth of 0.010 inch with the final blow of a hammer, without a center punch. Countersinking to this depth will leave no hammer marks in the wood if some care is exercised. The hole that remains in the underlayment after driving is approximately 1/10

inch in diameter, too small to cause dimpling of thin coverings even from spikelike shoe heels. If the underlayment should gain moisture and swell after nailing, the nail will only sink slightly deeper.

Because of its differential diameters and annular grooving, the new nail has greater holding ability in underlayment than in subflooring. The purpose of concentrating greater holding ability in the underlayment is to prevent nail popping. When underlayment and subflooring shrink during drying, a gap develops between the two layers of flooring. In effect, the underlayment is suspended above the subflooring by the holding ability of the shank of the nail in each layer of flooring. If the underlayment is subjected to an external load that exceeds the withdrawal resistance of the nail shank in the underlayment, then a nail pop equal to the distance of the gap between the underlayment and subfloor will occur. The new nail has been designed so that it will not fail in the underlayment and cause such a pop. Thus, if excessive loads should be applied to a suspended underlayment, the upper shank of the nail would hold firmly in the underlayment because of its greater withdrawal resistance and the lower shank, because of its lower push-through resistance, would slip downward in the subfloor where nail protrusion would not be visually objectionable. Once the nail had slipped in the subfloor, the annular grooves in the lower shank would still provide a high resistance to withdrawal. The amount of nail slippage in the subfloor would be no greater than the distance of the initial gap between the two layers of flooring.

LABORATORY TESTING

Four laboratory tests provided a preliminary evaluation of the prototype nail. Their overall purpose was to determine if the nail would remain embedded and provide adequate holding ability when plywood underlayment and subflooring were subjected to conditions simulating severe service. The first test was designed to measure outward or inward movement of the nail as the plywood flooring underwent severe and repeated changes in moisture content and dimension. The second test, which utilized the exposed specimens from the first test, was devised to measure the tension force required to separate the underlayment and subflooring when they were held together by a single nail, thus indicating the nail's long-term holding ability. In the third test, the resistance to withdrawal and pullthrough of the nail was measured in plywood underlayment and subflooring preconditioned to a relatively normal moisture content. The fourth test was designed to show any loss in holding ability which might occur when the nail was driven into plywood at a high moisture content and withdrawn after the plywood had been dried to a low moisture content.

Because only 30 of the nails were produced for testing, it was necessary to reuse them in each test. Each test nail was machined on a lathe from a flat-headed, 16d common nail of low-carbon steel. The resulting nails were of the configuration and dimensions shown in figure 3 except that the flat heads from the original nails were not cut away from the shanks. These original heads were left intact to facilitate gripping during

the tests of axial withdrawal and measurements of cumulative creep during cyclic exposure. Because these heads were positioned above the grooved shanks of the test nails, they in no way affected the results of the tests.

Test I: Resistance to Cumulative Creep

Methods

Twenty-seven specimens were prepared, each consisting of two 3- by 6-inch pieces of 5-ply southern pine plywood fastened together with a single test nail. The top piece was 5/8-inch-thick underlayment-grade plywood, and the lower piece was 1/2-inch-thick sheathing-grade plywood.

Before the pieces of plywood were fastened together with the test nails, the underlayment had been preconditioned to an average equilibrium moisture content (E.M.C.) of 5.0 percent at 90±3° F. and 30±5 percent relative humidity, and the subflooring had been preconditioned to an E.M.C. of 9.9 percent at 90±3° F. and 50±5 percent relative humidity. These two moisture contents represent unusually dry conditions for nailing such flooring materials together at a job site. However, the purpose of this procedure was to cause extreme expansion of both pieces of plywood during the high-humidity phase of the first moisture cycle, thereby attempting to force the nail into an extreme amount of outward creep. The subsequent low-humidity phase of the cycle would then cause the head of the nail to protrude as much as possible while the plywood shrank.

After the nails were driven into the preconditioned plywood, the distances between the heads and the upper surface of the underlayment and between the points and the lower surface of the subflooring were measured to the nearest 0.001 inch with a dial micrometer on a specially constructed base. The stem and contact point of the micrometer had been fitted into a hole through a machined base of solid brass. The flat bottom of the base was then placed on the surface of the plywood so that the head or point of the nail projected into the hole where the contact point could rest upon it.

After these initial measurements, the assembled specimens were subjected to three complete cycles of high and low relative humidity extending over a 6-month period. During the high-humidity phase of each cycle, the specimens were exposed at 90±3° F. and 90±5 percent relative humidity and reached an E.M.C. of about 19 percent within 4 weeks. During the low-humidity phase, they were exposed at 90±3° F. and 30±5 percent relative humidity and reached an E.M.C. of about 6 percent within 4 weeks. The positions of the nailheads and points were remeasured with the dial micrometer at the completion of each phase of the three cycles.

Results and Discussion

The results of this test for resistance to cumulative creep are summarized in table 1. At no time during the three moisture cycles did the heads or points of any of the 27 nails creep outward beyond their initial

Table 1.--Average change from the initial distances between the heads of 27 test nails and the surface of the underlayment and between the nail points and the subflooring after each phase of three moisture cycles

Relative humidity (percent)	Change in distance from--	
	Nailhead to underlayment[1]	Nail point to subflooring[1]
	- - - - Inch - - - -	
90	-0.013	-0.009
30	- .005	- .002
90	- .013	- .009
30	- .004	- .001
90	- .021	- .019
30	- .008	- .005

[1] The initial distances that the nailheads projected above the underlayment and the points projected below the subflooring were arbitrarily defined as zero. Negative values therefore indicate the amount of decrease from these initial distances at the end of each phase of the moisture cycles.

distances from the plywood surfaces. Instead, because of the expansion of the underlayment and subflooring, the average distance between the nailheads and the underlayment was reduced by 0.013 inch during the high-humidity phase of the first cycle, and the heads did not regain their initial distance during subsequent cycles. The average decrease from the initial distance of the heads was 0.021 inch after the high-humidity phase of the third cycle because of poor control over relative humidity and greater-than-normal expansion of the underlayment and subflooring. After the dry phase of each cycle, the nailheads and points tended to return to their initial distances, although a complete return never occurred. At the completion of the dry phase of the final cycle, the average decrease from the initial distance of the heads was 0.008 inch.

It can be seen from this test that, because the new nail is of headless design, the plywood can expand and contract without the nail's being withdrawn. Had an ordinary nail with a flat head been driven flush with the underlayment, expansion of the underlayment might have exerted enough pressure on the underside of the head to cause the nail's withdrawal from the underlayment and subflooring. Then, with subsequent shrinkage of the plywood, the flat head would have remained above the surface of the underlayment and caused surface irregularities. On the other hand, had a flat-headed nail with enough withdrawal resistance to remain fixed during expansion been used, the embedded head might have caused a dimple in the surface plane. With the new headless nail, neither of these alternatives occurs.

Test II: Resistance to Separation of Flooring Members

Methods

The tension forces required to separate the underlayment from the subflooring in each of the 27 specimens previously exposed to cyclic conditions were measured with a testing machine. The average moisture content of the wood was 6.3 percent at the time of testing. Each specimen was adapted for this tension test by twisting the pieces of underlayment and subflooring about the axis of the nail so that the long dimensions of the two pieces were perpendicular to one another. This modified speci-

men had the configuration of a typical specimen for the cross-lap tension test. Loading simply involved application of a compression force to the ends of the subflooring while the underlayment was supported at its ends. The specimens were loaded at a constant rate of 0.10 inch per minute until the maximum load was reached.

Results and Discussion

The tension force required to separate the underlayment from the subflooring in these specimens is shown in table 2. The average force required was 139 pounds when the average moisture content of the plywood was 6.3 percent. Although no measurements of holding ability in these specimens were made before the exposure tests began, some comparison can be made on the basis of the results of the following test.

Table 2.--Results of tests of the holding power of the test nails in plywood underlayment and subflooring

Test number and type	Specimens	Moisture content of specimens	Average load	Standard deviation of loads	Maximum load	Minimum load
	Number	Percent	Pounds			
II Resistance to separation of underlayment and subflooring	27	6.3	139	19	189	113
III Resistance to withdrawal from underlayment	30	9.5	249	37	360	192
Resistance to withdrawal from subflooring	30	9.5	134	33	203	80
Resistance to pullthrough in underlayment	15	9.7	161	25	203	122
Resistance to pullthrough in subflooring	15	9.7	80	24	125	49
IV Resistance to withdrawal from underlayment:						
Before drying	15	19.2	207	21	245	176
After drying	15	6.8	153	29	205	107
Resistance to withdrawal from subflooring:						
Before drying	15	19.2	160	24	219	127
After drying	15	6.8	94	23	144	52

Test III: Withdrawal and Pullthrough Resistance

Methods

Thirty nails were tested for axial withdrawal resistance in plywood underlayment and subflooring that had been preconditioned to an average E.M.C. of 9.5 percent at 70±3° F. and 50±5 percent relative humidity.

These nails were first driven into the centers of thirty 3- by 6-inch pieces of 5/8-inch-thick underlayment. The upper shanks of the nails were completely embedded in the underlayment, as would be typical in a floor installation. The nails were then tested for axial withdrawal resistance in a standard tension-loading assembly (1). Loads were applied with a testing machine at a crosshead speed of 0.10 inch per minute.

When the withdrawal test in the underlayment was completed, the same nails were driven into 30 preconditioned 3- by 6-inch pieces of 1/2-inch-thick plywood subflooring. The heads projected 5/8 inch above the upper surface of the plywood. Positioning of the nails corresponded with normal placement in a typical underlayment-subfloor system. The nails were then tested for axial withdrawal resistance as previously described.

After completion of the withdrawal tests, the same nails were tested for pullthrough resistance in plywood underlayment and subflooring that had been preconditioned to an average E.M.C. of 9.7 percent at 70 ± 3° F. and 50 ± 5 percent relative humidity. Fifteen specimens of underlayment and 15 of subflooring were prepared, and the nails were driven as described above. Immediately after driving, the pullthrough resistances of the upper and lower shanks of these nails were tested in the respective flooring materials. A simple compression-loading apparatus was devised so that the loads could be applied to the nailheads and thus push the nails through the flooring materials. The nails were loaded at the rate of 0.10 inch per minute.

Results and Discussion

The results of this test are summarized in table 2. When driven into the underlayment at 9.5 percent moisture content, the upper shanks of the 30 nails averaged 249 pounds in withdrawal resistance. When driven into the subflooring at the same moisture content, the lower shanks averaged 134 pounds in withdrawal resistance. The average pullthrough resistance of the upper shanks of the 15 nails embedded in the underlayment was 161 pounds, whereas that of the lower shanks of the 15 nails driven into the subflooring was 80 pounds.

The new nail was designed to provide greater holding ability in the upper shank than in the lower shank, primarily to insure that no nail failures would occur in the underlayment. Thus, if any nail failure occurred, it would always be in the subflooring where such a failure would not be visually objectionable. The results of test III demonstrate this difference in the holding abilities of the two shanks.

These results also provide some basis for comparing the holding ability of the specimens before and after exposure to moisture cycles. It will be recalled that in test II, which was conducted with specimens that had previously been exposed to three moisture cycles, the average tension force required to separate the underlayment from the subflooring was 139 pounds when the moisture content of the specimens averaged 6.3 percent. In the present test, the average withdrawal resistance of the

nails driven into and immediately withdrawn from subflooring at a moisture content of 9.5 percent was 134 pounds, and the immediate pullthrough resistance of the nails driven into underlayment at the same moisture content averaged 161 pounds. Comparison of the results of these two tests thus provides some evidence that the nails retained most of their original holding ability even after severe changes in moisture content.

Test IV: Withdrawal Resistance After Drying

Methods

The axial withdrawal resistance of the new nails immediately after they had been driven into plywood at a high moisture content was compared with their resistance after they had remained in the plywood until it dried to a low moisture content. Two nails were driven into each of fifteen 3- by 6-inch pieces of plywood underlayment that had been preconditioned to an average E.M.C. of 19.2 percent at 90±3° F. and 90±5 percent relative humidity. The upper shanks of the nails were completely embedded in the underlayment. Immediately after driving, one nail from each of the 15 pieces was withdrawn by the tension-loading assembly at a crosshead speed of 0.10 inch per minute. The 15 pieces were then dried for 6 weeks at 90±3° F. and 30±5 percent relative humidity to an average E.M.C. of 6.8 percent. The remaining 15 nails were then withdrawn as outlined above. The same procedure was followed in testing the withdrawal resistance of the lower shanks of the nails in plywood subflooring.

Results and Discussion

The results of this test are summarized in table 2. The upper shanks of the 15 nails in the underlayment at a moisture content of 19.2 percent averaged 207 pounds in withdrawal resistance. After the underlayment had dried for 6 weeks to a moisture content of 6.8 percent, the withdrawal resistance of the upper shanks of the 15 remaining nails averaged 153 pounds, a 26-percent loss in holding ability. The lower shanks of the 15 nails in subflooring at a moisture content of 19.2 percent averaged 160 pounds in withdrawal resistance. After the subflooring had dried to a moisture content of 6.8 percent, the withdrawal resistance of the lower shanks of the 15 remaining nails averaged 94 pounds, a 41-percent loss in holding ability.

These losses in withdrawal resistance during drying were greater than anticipated. The problem can be rectified with slight changes in the design of the nail. One possibility is to decrease the depth of grooving in both the upper and lower shanks so that the wood filling the grooves will be in firmer contact with more of the nail's surface. Another is to increase the contact of the nail with the wood by machining each groove to a double

shoulder, as was done in the Stronghold[1] annular-grooved nail (3, p. 7). Such problems will be dealt with as further work in design and testing proceeds.

CONCLUSION

The preliminary tests indicate that the new nail will effectively prevent nail popping and dimpling in flooring of thin resilient tiles. They further indicate that the nail is highly resistant to withdrawal from plywood underlayment and subflooring, even after severe changes in moisture content of the wood. An investigation is underway to determine the feasibility of producing the new nail economically by a commercial process. If such a process is found to be practical, this nail, along with nails of slightly different designs, will be mass-produced commercially in sufficient numbers for extensive testing in the laboratory and in the field. It is hoped that fastener manufacturers will become interested enough to attempt commercial exploitation.

[1] The use of trade names in this article is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval of any product by the United States Department of Agriculture to the exclusion of others that may be suitable.

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Vick, Charles B., and Walker, Roy M.
1972. A new nail to eliminate nail popping and dimpling under resilient tile flooring. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-102, 14 pp.

A headless nail with annular grooving and differential diameters in the upper and lower shanks has been designed for fastening plywood underlayment to subflooring. When used properly, the nail will effectively eliminate objectionable nail popping and dimpling in flooring of smooth-surfaced resilient tiles. Preliminary tests in the laboratory with handmade prototypes also indicate that the nails are highly resistant to withdrawal, even after severe changes in moisture content of the wood.

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DA Forest Service Research Paper SE-103 January 1973

Growth of Two Varieties of Slash Pine n Prepared Sites in South Florida: 10-Year Results

by

Michael R. Lennartz

and

James W. McMinn

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U.S. Department of Agriculture - Forest Service
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Growth of Two Varieties of Slash Pine on Prepared Sites in South Florida: 10-Year Results

by

Michael R. Lennartz, Wildlife Biologist
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INTRODUCTION

Mechanical site preparation prior to planting pines is a commonly employed silvicultural practice in the southeastern Coastal Plain. As site preparation is a costly part of plantation establishment and maintenance, land managers are interested in knowing how varying levels of site disturbance affect such important factors as survival and timber growth.

In January of 1958, 1959, and 1960, the Southeastern Forest Experiment Station, in cooperation with the Alico Land Development Company and Agrico, Inc., established a study in south Florida to evaluate the influence of selected site treatments on the survival and growth of typical slash pine (Pinus elliottii var. elliottii) and South Florida slash pine (Pinus elliottii var. densa Little & Dorman). A second objective was to compare the performance of these varieties under conditions of the study. McMinn[2] reported the results of the study through the fifth year after planting. This report presents findings through the tenth year.

METHODS

This study was established on flatwoods sites near Corkscrew, Frostproof, and Pierce, Florida (fig. 1). The flatwoods soils are characterized by nearly level, acid sands with poor surface drainage and are underlain either by marl or an organic pan. They are subject to both drought and flooding. The predominant shrub is saw-palmetto (Serenoa repens (Bartr.) Small), and the most common herbaceous cover is pineland threeawn (Aristida stricta Michx.).

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[1] Now located at Asheville, North Carolina.

[2] McMinn, J. W. Preparing sites for pine plantings in south Florida. Southeast. For. Exp. Stn., USDA For. Serv. Res. Note SE-117, 5 pp. 1969.

Mention of trade names in this paper is for identification only and does not imply endorsement by the U. S. Department of Agriculture.

Figure 1.--Location of study sites in Florida.

Site preparations included burning, strip-chopping, double-chopping, clearing, and bedding. Control plots were untreated.

Burning consisted of a prescribed burn with no additional treatment.

Strip-chopping was accomplished by drawing a Marden L-7 Duplex Light Brush Cutter on 10-foot centers over unburned plots with a crawler tractor. The effect was to cut and mix vegetation into the soil with some scarification, but no inversion, of the topsoil (fig. 2).

Double-chopping consisted of chopping the plot twice with the Marden L-7, the second chopping immediately after the first and perpendicular to it.

Clearing included prescribed burning, bulldozing the stumps, collecting the debris with a root rake and burning it, and harrowing the plots with a heavy-duty, offset-disk harrow (fig. 3).

Bedding consisted of plowing fireline furrows at 10-foot intervals on unburned plots so that the ridges thrown to each side of a furrow abutted the ridges of adjacent furrows. These abutting ridges, or "furrow slices," were then chopped to prepare smooth beds for planting. Bedding was not included in the study until the second year.

All treatments for a given planting were applied at about the same time. Site treatment generally preceded planting by 6 to 8 months, although the range was from 1 to 12 months.

Seedlings were planted during late December or in January of 1958, 1959, and 1960. Four replications of each site treatment were established for each location and year. Plots were established near Pierce only during the last 2 years. Each plot measured 4.2 acres and was planted to both typical slash pine and South Florida slash pine in a split-plot arrangement. Seedlings were planted with a drag-type tree planter at a spacing of 6 by 10 feet. Measurements and observations were made on 100 trees near the center of each subplot.

Figure 2. --The strip-chopping treatment.

Figure 3. --Cleared plot receiving final harrowing.

RESULTS

Height Growth

Site preparation significantly improved tenth-year height at five of eight plantings of typical slash pine and at six of eight plantings of the South Florida variety (table 1).

Table 1.--Heights of typical and South Florida slash pines 10 years after planting

Year planted	Location	Site treatment					
		Control	Burning	Strip-chopping	Double-chopping	Clearing	Bedding
		Feet					
TYPICAL SLASH PINE							
1958	Corkscrew	18.7	18.6	19.1	19.4	19.4	--
1958	Frostproof	14.1	18.0*	16.1	19.0*	22.3*	--
1959	Corkscrew	19.2	21.3	21.4	20.2	23.2*	23.7*
1959	Frostproof	15.0	15.9	15.4	18.1	17.9	19.3*
1959	Pierce	33.8	27.2	28.8	28.2	25.2	28.0
1960	Corkscrew	22.2	21.4	22.9	22.9	22.4	22.9
1960	Frostproof	19.5	19.8	21.7	23.8	24.6*	23.4
1960	Pierce	26.8	27.4	28.7	30.4*	31.3*	33.2*
	Average (1959-60)[1]	22.8	22.2	23.2	23.9	24.1	25.1
SOUTH FLORIDA SLASH PINE							
1958	Corkscrew	14.2	12.2	12.2	14.0	14.4	--
1958	Frostproof	10.3	13.0	10.4	15.6*	15.3*	--
1959	Corkscrew	17.4	20.0	19.0	21.2*	24.2*	26.0*
1959	Frostproof	11.3	12.7	12.4	16.2*	15.7*	13.7
1959	Pierce	23.2	30.8	22.4	25.0	23.8	27.0
1960	Corkscrew	15.9	15.2	15.8	19.1*	19.2*	18.1
1960	Frostproof	13.3	16.1	15.8	16.3	18.4*	18.9*
1960	Pierce	20.0	20.4	21.6	23.0*	25.0*	28.0*
	Average (1959-60)[1]	16.9	19.2	17.8	20.1	21.1	22.0

*Significantly different from the control at 0.05 level by Duncan's test.
[1] Years which included all locations and treatments.

Generally, growth response was related to the degree of disturbance or reduction in competing vegetation. Clearing and bedding produced the best improvement in growth. Double-chopping significantly improved growth at several locations, but the response was not as great nor as consistent as that achieved with bedding and clearing. Strip-chopping produced no significant improvement in height growth, and burning resulted in improvement at only one location and in a single year.

Many of the height differences developed the first 5 years after planting,[3] but growth from the fifth through the tenth year was also significantly increased by site preparation (table 2).

[3] Ibid.

Table 2.--Height growth of typical and South Florida slash pines from the fifth through the tenth years after planting

Year planted	Location	Site treatment					
		Control	Burning	Strip-chopping	Double-chopping	Clearing	Bedding
		Feet					
TYPICAL SLASH PINE							
1958	Corkscrew	13.9	13.8	14.3	14.0	14.0	--
1958	Frostproof	10.2	13.2	11.9	13.3	15.1	--
1959	Corkscrew	12.4	13.9	13.5	13.9	14.6*	14.9*
1959	Frostproof	10.3	10.8	10.6	12.2	11.6	11.8
1959	Pierce	21.6	18.8	20.8	20.0	17.9	19.0
1960	Corkscrew	13.5	13.3	14.0	14.6	14.6	14.4
1960	Frostproof	12.2	12.7	13.7	15.1*	15.1*	12.4
1960	Pierce	18.0	18.8	19.2	19.9*	19.6*	18.0
	Average (1959-60)[1]	14.7	14.7	15.3	16.0	15.5	15.1
SOUTH FLORIDA SLASH PINE							
1958	Corkscrew	10.5	9.8	9.8	11.3	11.5	--
1958	Frostproof	8.1	9.6	8.0	11.5	11.9	--
1959	Corkscrew	12.9	15.0*	14.5	15.6*	16.9*	17.9*
1959	Frostproof	8.1	9.0	9.0	11.4	9.7	8.6
1959	Pierce	16.6	17.2	17.2	17.8	17.9	17.6
1960	Corkscrew	11.4	11.1	12.0	14.5*	13.9*	12.9
1960	Frostproof	9.4	11.5	11.3	12.1	12.6*	11.1
1960	Pierce	15.6	15.8	16.2	16.9*	17.3*	17.6*
	Average (1959-60)[1]	12.3	13.3	13.4	14.7	14.7	14.3

*Significantly different from the control at 0.05 level by Duncan's test.
[1]Years which included all locations and treatments.

Five years after planting, bedding had significantly improved growth at four of six plantings of typical slash pine and at five of six plantings of the South Florida variety. From the fifth through the tenth year, however, significant increases in growth on bedded plots occurred on only one of six plantings of typical slash pine and on two of six plantings of South Florida slash pine. Response to the clearing treatment also decreased during the fifth- through tenth-year growth period, but the decrease was not as great as that for bedding. Response to double-chopping was similar during both measurement periods, but the cumulative effect at 10 years was not as great as that from either clearing or bedding. Figure 4 presents a general picture of treatment effects 5 and 10 years after planting.

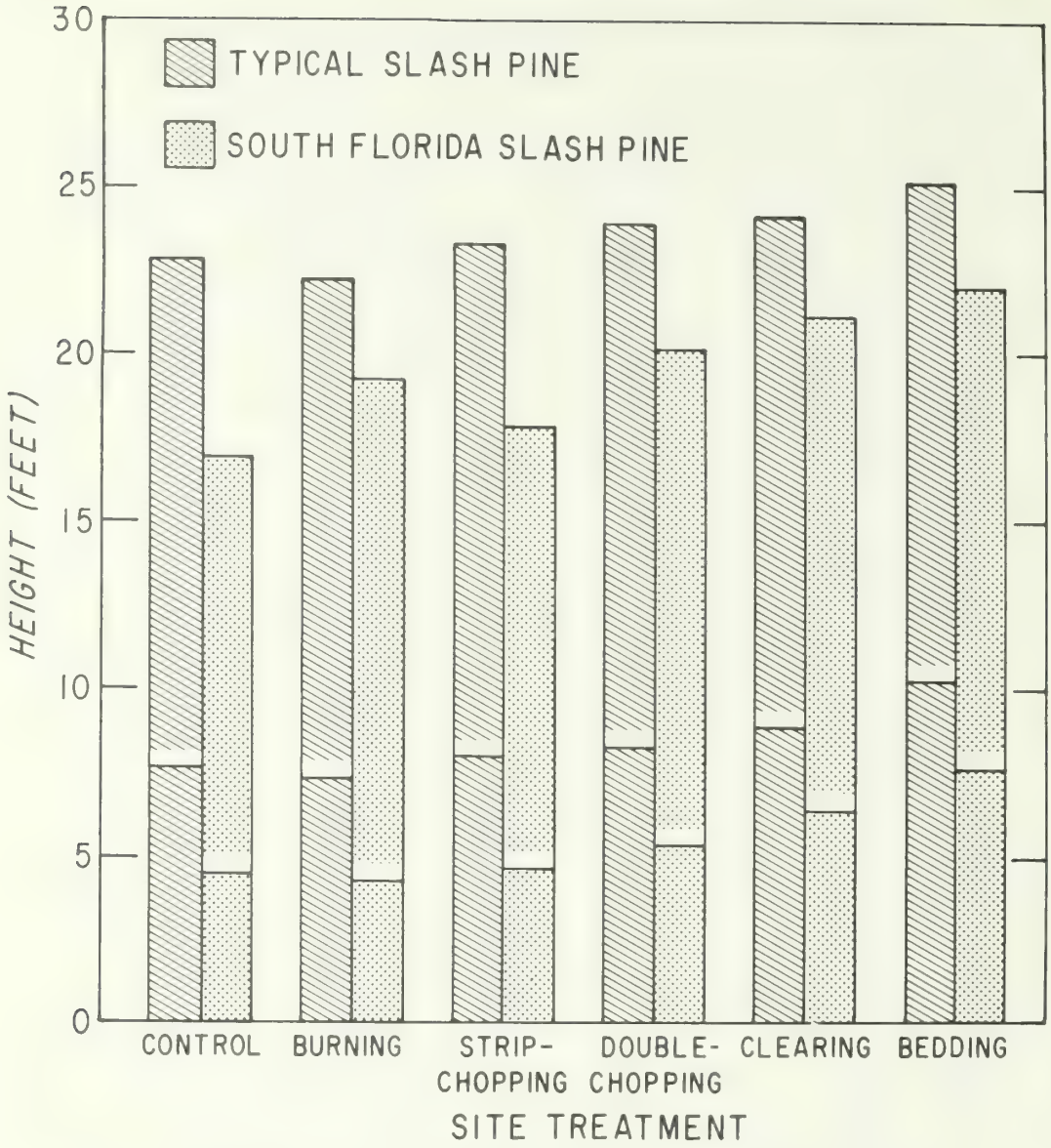

Figure 4.--Ten-year heights of typical and South Florida slash pines averaged for those years (1959-1960) which included all treatments and locations. (Breaks in bars indicate 5-year heights.)

Diameter

Site preparation also produced a significant response in diameter growth (table 3). At four of eight plantings of typical slash pine and five of eight plantings of the South Florida variety, site preparation resulted in significant improvement in growth over that of the control plots. Again, response appeared to be related to degree of site disturbance or reduction in competing vegetation. Generally, growth was best on cleared or bedded plots. Double-chopping resulted in significantly improved diameter increment at several locations, but the response was not as con-

Table 3.--Diameters of typical and South Florida slash pines 10 years after planting

Year planted	Location	Site treatment					
		Control	Burning	Strip-chopping	Double-chopping	Clearing	Bedding
		Feet					
TYPICAL SLASH PINE							
1958	Corkscrew	3.2	3.3	3.6	3.5	3.6	--
1958	Frostproof	2.6	3.5*	3.1	3.5	4.3*	--
1959	Corkscrew	3.0	3.6*	3.8*	3.4	4.1*	3.9*
1959	Frostproof	2.6	2.8	2.7	2.9	3.1	3.0
1959	Pierce	4.8	4.4	4.6	4.5	4.1	4.8
1960	Corkscrew	3.6	3.4	3.8	3.9	3.8	4.0
1960	Frostproof	3.1	3.1	3.3	3.7	3.9*	3.6
1960	Pierce	3.9	4.2	4.2	4.4	4.4*	4.6*
	Average (1959-60)[1]	3.5	3.6	3.7	3.8	3.9	4.0
SOUTH FLORIDA SLASH PINE							
1958	Corkscrew	3.0	2.9	2.9	3.5	3.3	--
1958	Frostproof	2.6	3.1	2.5	3.3*	3.7*	--
1959	Corkscrew	3.2	3.8*	3.2	4.0*	4.8*	4.4*
1959	Frostproof	2.4	2.7	2.9	3.4	3.3	2.9
1959	Pierce	5.1	5.8	4.4	4.8	5.0	5.3
1960	Corkscrew	3.1	3.3	3.0	4.0	3.9*	3.9*
1960	Frostproof	2.8	3.2	3.1	3.4	3.8*	3.6*
1960	Pierce	3.9	4.1	4.2	4.6*	4.7*	4.9*
	Average (1959-60)[1]	3.4	3.8	3.5	4.0	4.3	4.2

*Significantly different from the control at 0.05 level by Duncan's test.
[1] Years which included all locations and treatments.

sistent as that for clearing and bedding. Strip-chopping improved growth at only one location, and burning resulted in significant responses in only three cases.

Survival

Site preparation had not significantly improved survival at 5 years after planting,[4] and there was little change in percentage of survival at 10 years (table 4).

[4] Ibid.

Table 4.--Percentage of survival of typical and South Florida slash pines 5 and 10 years after planting

Location	Variety[1]	1958 planting		1959 planting		1960 planting	
		5 yr.	10 yr.	5 yr.	10 yr.	5 yr.	10 yr.
		Percent					
Corkscrew	TS	69	68	93	93	84	83
	SFS	38	33	77	76	36	35
Frostproof	TS	31	30	82	72	81	68
	SFS	18	17	65	49	34	31
Pierce	TS	--	--	81	81	77	77
	SFS	--	--	67	64	46	46

[1] TS = Typical slash pine. SFS = South Florida slash pine.

Although the 1959 and 1960 plantings at Frostproof showed a marked decline in survival from age 5 through age 10 for both slash pine varieties, the differences were spread evenly over the treatments, and no statistical analysis was conducted.

Varietal Differences

Overall height at 10 years averaged for all treatments at all locations varied significantly by variety. Typical slash pine averaged 22.2 feet, and South Florida slash pine averaged 17.9 feet:

Growth period	Typical	South Florida
(years from planting)	(height growth in feet)	
1 - 5	7.2	4.7
5 - 10	15.0	13.2
1 - 10	22.2	17.9

McMinn[5] noted in 1969 that "...observations of several 8- to 15-year-old plantations indicate the early lead established by typical slash may not be maintained for a full rotation." Ten-year results of this study lend little support to this conjecture, but it is still too early to tell.

At 5 years, height growth of typical slash pine was significantly greater than that of the South Florida variety at all locations. From the fifth through the tenth year, however, growth of typical slash pine was significantly greater at seven locations and that of South Florida slash

[5] Ibid.

pine was significantly greater at one. Whether or not growth of South Florida slash pine will actually meet or surpass that of typical slash pine later in the rotation remains to be determined.

There was no significant difference in diameter growth between the two slash pine varieties. At 10 years, both varieties averaged 3.7 inches in diameter. However, considering the initial density and the uniformly lower survival of the South Florida variety, the d.b.h. comparison may well be biased in favor of this variety.

DISCUSSION AND CONCLUSIONS

Site preparation resulted in significant improvement in both height and diameter growth of both varieties of planted slash pine in south Florida. Generally, improved growth was related to degree of disturbance or reduction in competing vegetation. Bedding provided the most favorable site for early growth (through 5 years), whereas clearing appears to have provided the most favorable environment for growth from the fifth through the tenth years. Clearing more drastically reduces competing vegetation, but bedding produces the additional effect of altering soil-water relations.[6] [7] It is possible that the improvements in soil moisture and aeration attributed to bedding have their greatest effect on tree growth during early stages of development or until root systems become fully developed. Then, as root mass increases to more fully utilize the site, competition with other vegetation may become the more important factor. When one views the differences in response between the strip-chopping, double-chopping, and clearing treatments, it appears that the degree of disturbance or reduction in competing vegetation is certainly an important factor in improving growth.

Because it is still too early to predict how the plantations will develop through rotation age, only the most tentative of recommendations can be made at this time. Under the conditions of this study, typical slash pine exhibited superior survival and height growth relative to the performance of the South Florida variety and, if present height differences are maintained, will produce more merchantable volume at rotation age. However, it does not appear that site preparation would be a profitable venture when planting typical slash pine. On the other hand, if the South Florida variety is to be planted, site preparation should be considered. If the height advantage demonstrated on the bedded plots is maintained over the rotation, the increase in merchantable volume will probably prove bedding to be a profitable practice in planting South Florida slash pine.

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[6] Ibid.

[7] McKee, W. H., Jr., and Shoulders, Eugene. Depth of water table and redox potential of soil affects slash pine growth. For. Sci. 16: 399-402. 1970.

As always, there are factors other than wood yield to be considered. Among them are degree of fire protection to the young plantation, ease of planting, multiple-use considerations, and improved working conditions during later cultural operations. The woodlands manager should carefully determine expected costs and returns for his specific situation prior to deciding for or against site preparation.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

DA Forest Service Research Paper SE-104 January 1973

Pollen Phenology and Dispersal Pattern for Shortleaf Pine in the Virginia Piedmont

by

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Pollen Phenology and Dispersal Pattern for Shortleaf Pine in the Virginia Piedmont

by

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Macon, Georgia[1]

INTRODUCTION AND METHODS

Although most of the research effort on flower production has been directed toward the initiation and development of the female strobili, the production, dispersal, and germination of pollen are equally important. This paper describes the phenology, densities, and germination of pollen in a natural stand of shortleaf pine (Pinus echinata Mill.) in the Virginia piedmont from 1963 through 1968. The study area was a 5-acre old-field stand of shortleaf pine on the Lee Experimental Forest in Buckingham County, Virginia. The trees observed for flower production and cone development averaged 26 years in age, 10.0 inches in diameter, 41 feet in height, and had 68 percent of their height in live crown in January 1968.

The basal area of the stand after thinning in 1962 was 30 square feet. The study area was adjacent to a 21-acre mixed stand of mature shortleaf and Virginia pines. Shortleaf pine is also prevalent throughout the 2,700-acre Experimental Forest and is represented in pure or mixed stands on approximately one-third of the area.

The pattern of pollen dispersal was determined by counting pollen grains collected on a total of 24 traps placed on two poles that were erected in the interior of the study area. On each pole, four pollen traps were placed at elevations of 10, 20, and 30 feet. At each height, one trap surface was exposed at a 45° angle to each of the cardinal directions. During the first year of study, vaseline-coated glass slides were used as pollen traps, but the pollen was difficult to count. In subsequent years, traps consisting of two tapes of adhesive celluloid, $\frac{1}{4}$ inch in diameter, were used (fig. 1).[2]

---

[1] Research conducted while the author was stationed at Blacksburg, Virginia.

[2] Hoekstra, P. E. A simple, inexpensive pollen trap. Southeast. For. Exp. Stn., U. S. For. Serv. Res. Note SE-40, 3 pp. 1965.

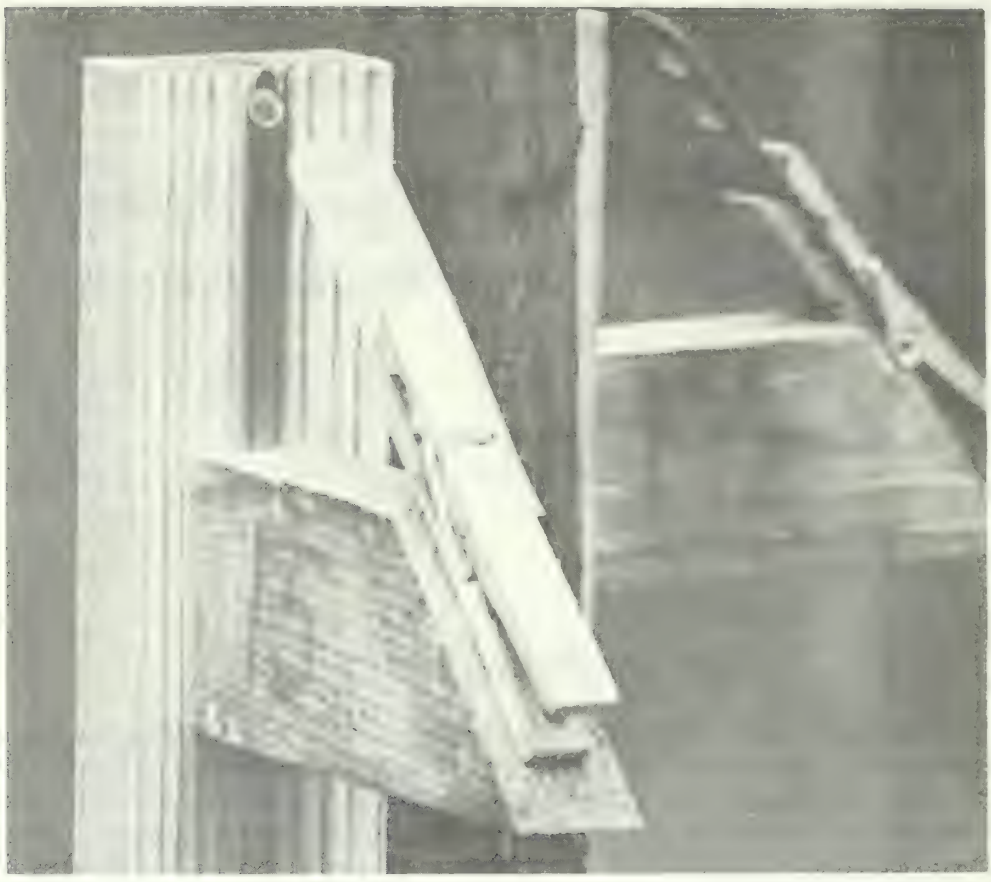

Figure 1.--Trap used to sample daily pollen dispersal in the shortleaf pine stand.

The pollen traps were exposed from about April 10 until approximately May 20, depending on whether the pollen season was early or late. These traps were exposed for a 24-hour period and changed daily at approximately 8 a.m. Pollen grains that adhered to the sticky surface were counted under 40x magnification.

Pollen germination was evaluated by collecting male strobili from the study trees just as they began to release pollen. The strobili were dried at room temperature for at least 24 hours, and the pollen was extracted. Small quantities of pollen from each tree were then dusted on agar droplets on a glass slide. The agar medium contained 0.75 percent agar (bacteriological grade) plus 10 percent sucrose in distilled water.[3] The glass slides were placed in a small staining dish with moistened

[3]Johnson, L. P. V. The storage and artificial germination of forest tree pollens. Can. J. Res. (Sect. C) Bot. Sci. 21: 332-342. 1943.

Table 1.--Dates of first release and maximum dispersal of pollen in a shortleaf pine stand in Buckingham County, Virginia

Year	Date	
	First release[1]	Maximum dispersal[2]
1963	April 28	May 5
1964	May 2	May 8
1965	May 6	May 9
1966	May 10	May 15
1967	April 30	May 3
1968	April 28	May 2

[1]Determined from daily observation of 10 trees.

[2]Determined from maximum pollen count.

filter paper, and the dish was sealed with vaseline to provide a moisture chamber of 100 percent relative humidity.[4] The pollen was allowed to germinate approximately 72 hours at room temperature. Germination counts were made by observing 200 pollen grains in arbitrarily chosen microscopic fields. A pollen grain was considered to have germinated when the length of the germ tube exceeded the diameter of the pollen grain.

RESULTS

The dates of first release and maximum dispersal of pollen in this stand of shortleaf pine are presented in table 1. The first day of release ranged from April 28 in 1963 and 1968 to May 10 in 1966. The date of maximum dispersal varied from May 2 in 1968 to May 15 in 1966. Despite this variation, the period of maximum dispersal coincided closely with receptivity of female flowers in all years of observation.

Nearly all the pollen was discharged during a 7-day period that included 3 days before and 3 days after the date of maximum dispersal. The density of pollen during each day of this 7-day period is presented in figure 2 for the years 1963 through 1968. Considerable variation occurred between years. During 1964, 1965, 1966, and 1968, more than 4,000 pollen grains per square inch were produced on the maximum day, whereas only 417 and 931 grains per square inch were produced during 1963 and 1967. The 3-day and 7-day total densities for these years show a similar pattern: densities were much higher in 1964, 1965, 1966, and 1968 than in 1963 and 1967 (table 2). The 7-day total of 17,462 grains per square inch in May 1968 represents an extremely high quantity of pollen available to the female flowers.

Analysis of variance indicated significant effects of year, location, elevation, and directional orientation on pollen catch (table 3). A greater density of pollen was consistently collected on pole 1 than on pole 2. The difference was not large and may represent proximity to heavy pollen producers. The average pollen density was higher at elevations of 10 and 20 feet than at the 30-foot elevation. Again, even though a statistically significant difference was present between elevations in the analysis of variance, the actual numerical differences were not large. The height at which the pollen is released in the tree would tend to favor the lower elevations. Although pollen is quite buoyant, it does settle rapidly in still air.

[4]Snyder, E. Bayne. Extracting, processing, and storing southern pine pollen. USDA For. Serv. South. For. Exp. Stn. Occas. Pap. 191, 14 pp. 1961.

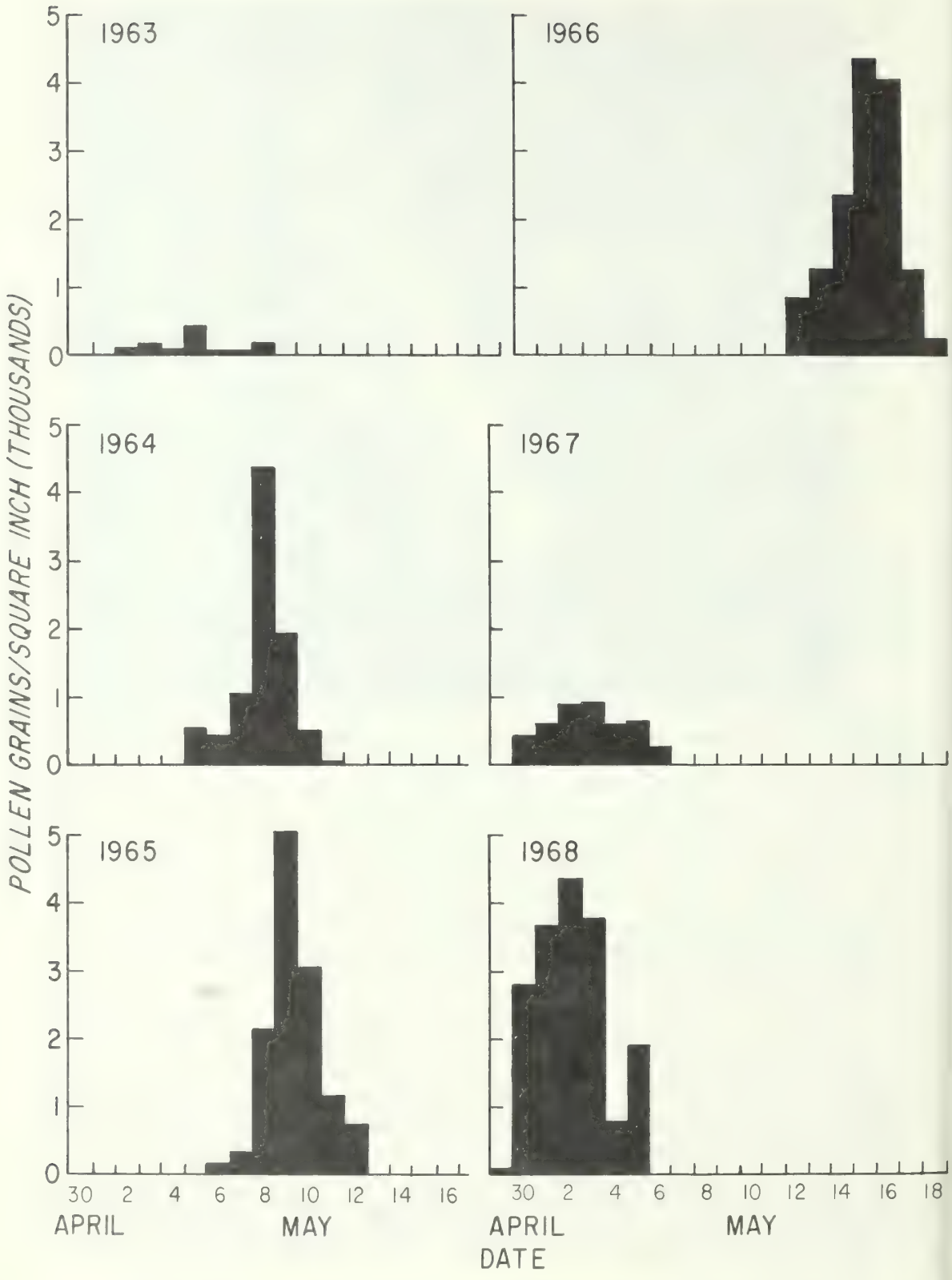

Figure 2.--Pattern of pollen dispersal in the shortleaf pine stand from 1963 through 1968.

Table 2.--Average density of pollen in the shortleaf pine stand over 1-, 3-, and 7-day periods, 1963-1968

Sample	Maximum day	3 days[1]	7 days[2]
	Number of grains/sq. in.		
Location			
Pole 1	3,522	7,938	10,576
Pole 2	2,968	6,454	9,068
Elevation			
10 feet	3,454	7,459	10,077
20 feet	3,357	7,447	10,185
30 feet	2,924	6,683	9,204
Orientation			
North	3,547	7,491	10,105
West	2,727	6,466	9,032
South	4,317	9,248	12,182
East	2,389	5,578	7,969
Year			
1963	417	587	1,087
1964	4,365	7,323	8,915
1965	5,075	10,279	12,648
1966	4,308	10,722	14,330
1967	931	2,477	4,490
1968	4,375	11,789	17,462

[1] Includes maximum day plus the day that preceded and the one that followed.
[2] Includes maximum day plus the 3 days that preceded and the 3 that followed.

Orientation of the pollen trap had the greatest effect on the quantity of pollen collected. The south-oriented traps were considerably higher in pollen density, whether over 1-, 3-, or 7-day periods. The traps orientated to the east received the lowest pollen densities. This directional influence on pollen collection is probably a reflection of the prevailing wind direction and the local supply of pollen. In addition, the interaction between year and orientation was significant at the 0.001 level. This interaction would be expected because pollen disperses only for a short time and wind direction could be expected to vary from year to year.

Pollen germination from the selected trees was consistently good. The average percentages of germination were 94, 98, 94, 86, 94, and 93 for the years 1963-1968. In 1967 and 1968, germination was high but de-

Table 3.--Analysis of variance for pollen density over a 7-day period in the shortleaf pine stand

Source	d.f.	MS x 10^3	F	P
Location	1	81,784	363.48	<0.001
Elevations (E)	2	13,906	61.91	.016
Error I	2	225		
Orientation (O)	3	116,512	66.15	< .001
E x O	6	2,581	1.46	.27
Error II	9	1,761		
Years (Y)	5	922,674	523.86	< .001
Y x E	10	2,694	.98	.55
Y x O	15	9,666	3.53	< .001
Y x O x E	30	1,006	.37	.97
Error III	60	2,742		
Total	143			

velopment of germ tubes was poor. Excessive handling of the pollen during transit from the Experimental Forest to the laboratory could account for the development of short germ tubes.

DISCUSSION

Although there was considerable variation in annual pollen production, total pollen density for the 7-day period would appear to be adequate for effective pollination even during the lowest year recorded. Germination rates were consistently high and did not appear to be a serious block to the total reproductive efficiency. Nonetheless, approximately 23 percent of the total ovules in each mature cone aborted during the first year.[5] These ovules apparently did not receive viable pollen.[6 7] Thus, the pollination efficiency was about 77 percent over the 6-year period. A large percentage of these aborted ovules were either at the top of the cone or near the lower whorls of fertile scales, indicating that these scales may not be quite as favorably located as the middle scales for the trapping of windblown pollen. Sarvas[7] noted a similar distribution of unpollinated ovules in Scotch pine cones.

[5]Bramlett, David L. Seed and aborted ovules from cones of Pinus echinata. Ga. For. Res. Counc. Res. Pap. 71, 5 pp. 1972.

[6]McWilliam, J. R. Interspecific incompatibility in Pinus. Am. J. Bot. 46: 425-433. 1959.

[7]Sarvas, Risto. Investigations on the flowering and seed crop of Pinus silvestris. Commun. Inst. For. Fenn. 53, 198 pp. 1962.

The date of initial pollen release or the date of maximum release could affect the reproductive success of shortleaf pine, because the probability of spring frosts is reduced when the pollen season is delayed. Pollen dispersal and receptivity of female flowers were well synchronized whether the pollen season was early or late.

The significant differences between location, elevations, and orientations of the pollen traps indicate that the pollen is not uniformly distributed in the stand. However, because of the large quantities of pollen present, the unequal distribution of pollen in this stand of shortleaf pine should not be an important factor influencing seed yield.

☆U.S. G.P.O.: 1973—747-095/6246, Region No. 4

Brambley, David L.
1995. Pollen phenology and dispersal patterns for shortleaf pine in the Virginia piedmont. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-184, 7 pp.

The phenology and pattern of pollen dispersal in a natural stand of shortleaf pine (*Pinus echinata* Mill.) in the Virginia piedmont were observed from 1987 through 1994. Date of initial dispersal ranged from April 28 in 1987 and 1988 to May 10 in 1994. Number of pollen grains collected per square inch on traps over a 5-day period varied from 1,087 in 1987 to 17,362 in 1994. The influences of year, location, elevation, and directional orientation of the transect on the density of pollen collected were statistically significant. Pollen germination was consistently high for all years of observation.

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USDA Forest Service Research Paper SE-105 February 1973

AN ANALYSIS of the Air Force Bomb Range Fire

by

Dale D. Wade

and

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U. S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Cover photographs--Total involvement of the fuel and abundant firebrands contributed to the initial 14-mile run of the Air Force Bomb Range Fire in eastern North Carolina. After the passage of a cold front, the southeastern flank formed two major heads, with one head stopping within 100 yards of the town of Stumpy Point.

ACKNOWLEDGMENT

The authors wish to thank the following people and organizations for their various contributions: Dane Roten and other employees of the North Carolina Forest Service for providing maps, photographs, fire reports, interviews, and other information concerning the area, fuels, and subsequent fire behavior and control; Dale N. Ellis, Fire Weather Forecaster for North Carolina, for providing weather data, charts, and related information; Quentin Bell and other personnel of the Westvaco Corporation for maps, photographs, and other pertinent information; and personnel of the U. S. Army Corps of Engineers and U. S. Air Force for an appraisal of fire damage and photographs.

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AN ANALYSIS of the Air Force Bomb Range Fire

by

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INTRODUCTION

There are few places in the world where wildfire behavior can be studied strictly as it is affected by weather variables, both ambient and fire-induced. Eastern North Carolina offers this opportunity. Large, homogeneous expanses of highly combustible fuel exist on land that has a maximum elevation of 10 ft. (3 m.) above mean sea level.[1] Fine fuel weights of 15 tons/acre (33.6 M.T./ha.) are common, and under extreme drought conditions these fuel weights may more than double as the peat soils, characteristic of this region, dry to depths of 1 to 2 ft. (0.3 to 0.6 m.).

Wildfires occurring in eastern North Carolina frequently become dangerously explosive, blowup fires. The 29,300-acre (11,860-ha.) Air Force Bomb Range Fire of March 22-26, 1971, was such a fire; it was studied by a fire documentation team from the Southern Forest Fire Laboratory. The fire exhibited several blowup features including high-density, short-distance spotting, a well-developed convection column, and rates of spread exceeding 2 m.p.h. (0.9 m./sec.) during a 4-hour period with a maximum of almost 5 m.p.h. (2.2 m./sec.) during one 4-mile (6.4-km.) run. The fire traveled 14 miles (22.5 km.) prior to the passage of a cold front, then changed direction, and ran an additional 6 miles (9.7 km.) as a post cold-frontal fire. A record of fire behavior was imprinted on the area vegetation in the form of concentric bands of unconsumed fuel that outlined the fire during the first 4 hours after ignition. Fire suppression was hampered by the poor trafficability of the soils, the heavy fuels, and the rapid rate of fire spread.

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[1]Metric equivalents appear in parentheses. See Appendix for conversion factors.

BACKGROUND

The inaccessibility of pocosins[2] contributes to the development of tremendously large fires such as the Lake Phelps Fire that burned 250,000 acres (101,175 ha.) during March and April 1955 and the Hyde-Tyrrell Fire that burned 100,000 acres (40,470 ha.) during April 1963. Other blowup fires have occurred during the summer (Bluff Point Fire--July 1952), fall (Hales Lake Fire--October 1952), wet periods (Pungo Lake Fire--April 1959), and drought periods (Dare County Fire--August 1957).

The area burned by the Air Force Bomb Range Fire contained a well-stocked natural stand of 13-year-old pond pine (Pinus serotina Michx.) and a dense pocosin understory, both of which developed after the lightning-caused 1957 Dare County Fire that denuded some 75,000 acres (30,350 ha.).

Dare County itself is a sparsely populated peninsula comprised primarily of pocosins and marshland. Most of the area is managed for forest production. A network of drainage canals and woods roads offers the only interruption in an otherwise unbroken expanse of fuel. Fire can travel in a truly uninhibited fashion.

Two military bomb ranges are located in the heart of the county, and both have a fire history because of the ordnance used. Several presuppression measures are taken to insure that any fires started will be confined to the target areas. A system of roads and canals acts as a fuel break and gives access (fig. 2). Fuel modification involving herbicides and prescribed fire and a suppression force composed of a helicopter and several tracked, cross-country vehicles have resulted in direct control of 137 of the 138 fires that occurred on the Air Force Bomb Range from 1965 through 1970. The average area burned was 0.5 acre (0.2 ha.).[3] The sole exception, prior to 1971, was a 3,600-acre (1,460-ha.) fire in April 1966.

FIRE DEVELOPMENT AND CONTROL

The stage was already set for a conflagration on March 22, 1971. During four of the preceding five days, the dead and cured fine fuels on the Air Force Bomb Range had been subjected to the desiccating effects of low humidities, moderate-to-fresh winds, and full sunshine. The Air Force Bomb Range Fire was ignited by a practice bomb dropped at 1028

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[2]"In general, pocosins may be described as those areas, including swamps and bays, with soils having 20 percent or more organic matter content, fair to poor internal drainage, and supporting stands of pond pine. Also, these areas have a medium to heavy density understory composed principally of woody shrubs and reeds. The pocosins constitute roughly 2 million acres in coastal North Carolina" (12, p. 3). See figure 1 for distribution of the principal areas of organic soil in eastern North Carolina.

[3]Green, H. J., Roten, Dane, and Plotkin, H. S. Air Force Bomb Range Fire. 17 pp. 1971. (Mimeogr. rep. of the Board Rev., N. C. For. Serv., Dep. Conserv. Dev.)

Figure 1.--Principal areas of organic soil in eastern North Carolina. The Air Force Bomb Range Fire and nearby weather stations are shown. [Soil map adapted from Wendel, Storey, and Byram (12).]

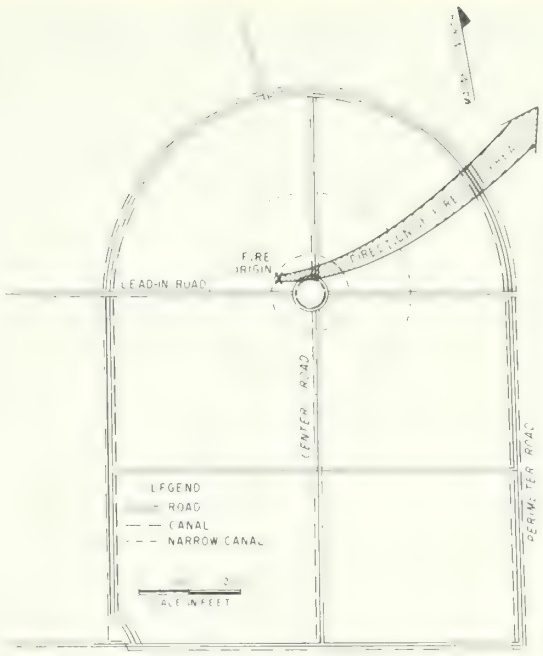

Figure 2.--The system of roads and canals used for access and fire control at the Dare County Air Force Bomb Range. Fire origin is marked by an "x."

e.s.t. and immediately became dominated by surface winds blowing at 20 m.p.h. (9 m./sec.). The fire was beyond control before the standby crew stationed on the range reached it.

The fire crowned through more than 15,000 acres (6,070 ha.) of pond pine during the next 20 hours and eventually burned 29,300 acres (11,860 ha.) of timber and nonforested watershed (fig. 3). The initial 14-mile (22.5-km.) run from the Air Force Bomb Range northeast to Croatan Sound produced a narrow, elongated shape typical of fires pushed by high winds. Rate of spread averaged over 2 m.p.h. (0.9 m./sec.) for 4 hours and nearly reached 5 m.p.h. (2.2 m./sec.) during a 1-hour period. The flanks remained active throughout the night of the 22nd until a cold front passed over the area before dawn on the 23rd. The resulting shift in wind direction from southwest to north created two heads from the southeast flank, one of which was pushed rapidly toward the town of Stumpy Point.

This sequence of events is typical of blowup fires in the South. They must be contained within a comparatively short time after ignition or suppression efforts become ineffectual. The fire will then remain uncontrollable until either fuel or weather conditions ameliorate, with a resultant decrease in fire intensity. In the case of the Air Force Bomb Range Fire, it was a change in fuel conditions that initially checked fire spread. One head lost its momentum in a wet, marshy area about 100

Figure 3.--Photo mosaic of the burned area. Outer solid line shows final perimeter o fire. Inner lines show fire perimeter at various times. The fire was controlled o March 26, 1971, at 29,300 acres (11,860 ha.).

yards (90 m.) north of Stumpy Point. The other also encountered wet conditions and was dissipated. Some flareups occurred along the northwest flank Tuesday and Wednesday, but, in general, the fire remained quiet until Friday, March 26, when a general rain occurred.

Even after the fire calmed down on Tuesday morning, the control force could not take full advantage of the situation. Because the water table was near the surface, the organic soils would not support tractor-plow units, and line building became an exceedingly difficult task. Lightweight, full-tracked, off-road vehicles such as Nodwells[4] equipped with portable pumps were used to trample down the brush along the fire perimeter. Then water was used to extinguish the active fire edge. At points where the vehicles did not proceed directly along the fire perimeter, their path of crushed brush was used as a baseline from which burning-out operations were initiated.

Fire development, behavior, and control, together with information on fuel and weather conditions between March 22 and March 26, are summarized in table 1.

FUELS

Pond pine, a fire-adapted species,[5] was the dominant overstory tree on the burn, averaging 1,250 stems/acre (3,100/ha.). About 64 percent of the forested area was covered with well-stocked, 13-year-old pond pine that came in after the 1957 burn (fig. 4). Another 13 percent contained poorly or medium-stocked, 13-year-old pond pine. The remainder was comprised of reproduction from the 1966 burn and older trees that survived the 1957 burn. In addition, 5,000 acres (2,025 ha.) of marsh, 5,000 acres (2,025 ha.) of low, open pocosin, and 1,200 acres (490 ha.) planted to species other than pond pine also burned.

The 13-year-old pond pine averaged 16 ft. (4.9 m.) in height and 2.9 inches (7.4 cm.) d.b.h. Its principal associates were redbay (Persea borbonia (L.) Spreng.) and sweetbay (Magnolia virginiana (L.)), which, together, averaged 13 ft. (4.0 m.) in height, 1.6 inches (4.1 cm.) d.b.h., and 220 stems/acre (550/ha.).

Species composition of the understory was variable. Wendel et al. (12) categorized pocosin fuels into 16 broad types on the basis of species composition of the understory, density, height, and age of rough. At least five of the types occurred on the burn area (table 2). The weight of fuel samples taken of types R-14, RB-10, and P-14 in the vicinity of the burn compared favorably with those given by Wendel et al. (12).

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[4] Mention of trade names throughout this Paper does not constitute endorsement by the U. S. Department of Agriculture.

[5] Among the fire adaptations of pond pine are its ability to produce viable seed at an early age, its serotinous cones, and its ability to sprout from both the root collar and the bole following defoliation by fire.

Table 1.--The Air Force Bomb Range Fire: Development, behavior, control, fuels, and weather between March 22 and 26, 1971

MONDAY, MARCH 22, 1971

Burning period (e.s.t.)	Fire status and control activities	Fire size, fuel, weather, and fire behavior
1028-1100		
1028	Fire ignited in dead brush and cured grass by practice bomb.	Fire size 8 acres (3 ha.)
1043	Bomb range closed.	Fuels Type[1]--GB-7
1047	Two cross-country vehicles manned by 5 men and equipped with portable pumps arrive at fire.	Weight--6.2 tons/acre (13.9 M.T./ha.)
1100	Fire crosses Center Road.	Weather at 1100[2]
		Wind--W20, gust 30 m.p.h. (W9, gust 13 m./sec.)
		Temp.--70° F. (21° C.), RH--34 percent
		Fire behavior
		Rate of spread--0.4 m.p.h. (0.5 km./hr.)
		Intensity[3]--835 B.t.u./ft./sec. (6,807 cal./cm./sec.)
		Total intensity[3]--0.03 x 10^7 B.t.u./sec. (7.6 x 10^4 cal./sec.)
1101-1226		
1130-1150	Two tractor-plow units arrive along Center Road and attack flanks. North flank soon becomes too hot for direct attack.	Fire size 155 acres (63 ha.)
1215	Crew starts suppression fire along Perimeter Road. Air observer arrives over fire.	Fuels Type[1]--GB-7
1226	Fire crosses Perimeter Road and begins crowning through young pond pine.	Weight--6.2 tons/acre (13.9 M.T./ha.)
		Weather at 1200[4]
		Wind--WSW20, gust 30 m.p.h. (WSW9, gust 13 m./sec.)
		Temp.--71° F. (22° C.), RH--28 percent
		Fire behavior
		Rate of spread--0.5 m.p.h. (0.8 km./hr.)
		Intensity[3]--1,042 B.t.u./ft./sec. (8,606 cal./cm./sec.)
		Total intensity[3]--0.18 x 10^7 B.t.u./sec. (45.4 x 10^4 cal./sec.)
1227-1439		
1230	Formation of an intermittent convection column begins.	Fire size 2,094 acres (847 ha.)
1245	Two Snow airtankers arrive and begin dropping retardant along the north flank. Retardant application discontinued because ineffective, and retardant planes placed in a hold pattern to be used for emergency drops.	Fuels Type[1]--RB-10, R-14, GB-7
		Weight--11.6 tons/acre (25.9 M.T./ha.)
		Weather at 1400[4]
		Wind--SW15, gust 20 m.p.h. (SW7, gust 9 m./sec.)
1439	Suppression firing crew reports from Jackson Road that fire has crossed Road.	Temp.--72° F. (22° C.), RH--25 percent
		Fire behavior
		Rate of spread--1.8 m.p.h. (2.9 km./hr.)
		Intensity[3]--7,006 B.t.u./ft./sec. (57,870 cal./cm./sec.)
		Total intensity[3]--2.81 x 10^7 B.t.u./sec. (708 x 10^4 cal./sec.)
1440-1537		
1440	Fire continues to crown through 13-year-old pond pine.	Fire size 2,975 acres (1,204 ha.)
1500	Fire crosses wet area between Jackson and Navy Shell Roads.	Fuels Type[1]--P-14, RB-10, R-14, GB-7
1537	Suppression firing crew reports from Navy Shell Road that fire has crossed Road.	Weight--10.8 tons/acre (24.3 M.T./ha.)
		Weather at 1500[4]
		Wind--SW15, gust 20 m.p.h. (SW7, gust 9 m./sec.)
		Temp.--71° F. (22° C.), RH--25 percent
		Fire behavior
		Rate of spread--0.8 m.p.h. (1.3 km./hr.)
		Intensity[3]--2,918 B.t.u./ft./sec. (24,102 cal./cm./sec.)
		Total intensity[3]--2.74 x 10^7 B.t.u./sec. (690 x 10^4 cal./sec.)

[1]Fuel types are listed in the table by descending amounts of acreage. GB-7 = grass--low brush, RB-10 = medium reeds--brush, R-14 = very high reeds, P-14 = high pocosin, P-5 = low pocosin--open.

[2]On-site reading.

[3]Intensity is defined as the rate of energy release per foot of fire front. Total intensity is defined as the total energy released per second by the fire during a given time period.

[4]Weather parameters estimated from readings at nearby weather stations.

MONDAY, MARCH 22, 1971

Burning period (e.s.t.)	Fire status and control activities	Fire size, fuel, weather, and fire behavior
1538-1636		
1538	Fire moves into denser fuels. About this time, surface winds back more to the south.	Fire size 6,518 acres (2,638 ha.)
1545	Convection column is maintained and builds to its maximum height of 15,000 ft.	Fuels Type[1]--P-14, RB-10, R-14, GB-7
1630	Suppression fire started along U. S. Highway 264.	Weight--11.4 tons/acre (25.6 M.T./ha.)
1636	Suppression firing crew reports from Highway 264 that fire is across Highway.	Weather at 1600[4]
		Wind--SSW20, gust 40 m.p.h. (SSW9, gust 18 m./sec.)
		Temp.--71° F. (22° C.), RH--25 percent
		Fire behavior
		Rate of spread--4.7 m.p.h. (7.6 km./hr.)
		Intensity[3]--18,116 B.t.u./ft./sec. (149,638 cal. cm./sec.)
		Total intensity[3]--11.44 x 10^7 B.t.u./sec. (2,883 x 10^7 cal./sec.)
1637-1745		
1700	Fuel becomes progressively wetter as the fire approaches Croatan Sound.	Fire size 9,796 acres (3,964 ha.)
1745	Fire about 2 miles beyond Highway 264 burning toward the Sound.	Fuels Type[1]--P-14, RB-10, R-14
		Weight--11.8 tons/acre (26.4 M.T./ha.)
		Weather at 1700[4]
		Wind--SW20, gust 30 m.p.h. (SW9, gust 13 m./sec.)
		Temp.--68° F. (20° C.), RH--32 percent
		Fire behavior
		Rate of spread--1.7 m.p.h. (2.7 km./hr.)
		Intensity[3]--6,747 B.t.u./ft./sec. (55,730 cal./cm./sec.)
		Total intensity[3]--6.33 x 10^7 B.t.u./sec. (2,351 x 10^7 cal./sec.)
1746-0400		
1900	Forward rate of spread stops because of wet fuel.	Fire size 17,386 acres (7,035 ha.)
2200	In anticipation of a 90° clockwise change in wind direction, the fire boss has crews burn out along the north side of roads located south of the fire. Very active flanking, particularly along the southeast flank.	Fuels Type[1]--P-14, R-14, Marsh grass
		Weight--12.1 tons/acre (27.1 M.T./ha.)
		Weather at 2400 on March 22, 1971[4]
		Wind--SW20, gust 30 m.p.h. (SW9, gust 13 m./sec.)
		Temp.--60° F. (16° C.), RH--50 percent
		Fire behavior
		Rate of spread--0.3 m.p.h. (0.3 km./hr.)
		Intensity[3]--816 B.t.u./ft./sec. (6,740 cal./cm./sec.)
		Total intensity[3]--2.46 x 10^7 B.t.u./sec. (620 x 10^7 cal./sec.)

TUESDAY, MARCH 23, 1971

0400	Cold front passes, and anticipated shift in wind direction occurs. The plowline from Perimeter Road to near Jackson Road stops fire from running south along this part of the fire. The remainder of the south flank becomes a head fire.	
0401-0530		
0430	Suppression fires set to save the town of Stumpy Point. Citizens evacuate homes.	Fire size 23,554 acres (9,53[illegible] ha.)
0500	Fire runs into marshy area and stops 100 yards (90 m.) short of Stumpy Point.	Fuels Type[1]--P-14, P-[illegible], R-14
0530	Fire crosses Lake Worth Road, runs out of dry fuel, and dies.	Weight--10.1 tons/[illegible] (22.[illegible] M.T./ha.)
		Weather at 0500[4]
		Wind--N17 m.p.h. (N7 m./sec.)
		Temp.--[illegible], (18° C.), RH--80 percent
		Fire behavior
		Rate of spread--1.3 m.p.h. (2.1 km./hr.)
		Intensity[3]--4,427 B.t.u./ft./sec. (36,[illegible] cal./cm./sec.)
		Total intensity[3]--1.67 x 10^7 B.t.u./sec. (2,184 x 10^7 cal./sec.)

[1]Fuel types are listed in the table by descending amounts of acreage. GB-7 = grass--low brush, RB-10 = medium red--brush, R-14 = very high reeds, P-14 = high porosity, P-[illegible] = low porosity--open.

[2]On-site reading.

[3]Intensity is defined as the rate of energy release per foot of fire front. Total intensity is defined as the total energy released per second by the fire during a given time period.

[4]Weather parameters estimated from records at nearby weather stations.

Table 1.--The Alligator Bank Range fire--Development, behavior, control, fuels, and weather between March 22 and 26, 1971 (continued)

TUESDAY, MARCH 23, 1971

Burning period (e.s.t.)	Fire status and control activities	Fire size, fuel, weather, and fire behavior
0441-1400 1700	Mop-up fire camp set up at Stumpy Point. Acreage lost during remainder of day because of flanking along northern perimeter. Fire control efforts directed toward line construction along the north flank. A canal running due east from Highway 264 is reinforced with retardants. Line construction is exceedingly difficult, with as many as 5 tractor-plow units plugged down at one time.	Fire size 24,600 acres (9,955 ha.) Fuels Type[1]--P-14 Weight--11.8 tons/acre (26.4 M.T./ha.) Weather at 1300 [2] Wind--N12 m.p.h. (N5 m./sec.) Temp.--49° F. (9° C.), RH--50 percent Fire behavior See fire status opposite
WEDNESDAY, MARCH 24, 1971		
0041-2400	Control activities directed toward burning out along the north side of the fire. A boat is sent down the canal to the Sound with orders to burn out south of the canal. The burnout operation is not completely successful as a result of higher humidities and the high water table. Several areas are partially burned out, as shown on the photo mosaic (fig. 4).	Fire size 29,300 acres (11,857 ha.) Fuels Type[1]--Marsh grass, GB-7, P-14 Weight--7.3 tons/acre (16.3 M.T./ha.) Weather at 1300 [2] Wind--N16 m.p.h. (N7 m./sec.) Temp.--45° F. (7° C.), RH--51 percent Fire behavior See fire status opposite
THURSDAY, MARCH 25, 1971		
0001-2400	Activities concentrated on strengthening and holding the fire perimeter. Anticipated change in wind direction to the east does not occur. (Orientation of the flanks is the same with a NE wind as with a SW wind.)	Fire size 29,300 acres (11,857 ha.) Weather at 1300 [2] Wind--NE8 m.p.h. (NE4 m./sec.) Temp.--44° F. (7° C.), RH--30 percent
FRIDAY, MARCH 26, 1971		
0001-1000	With the occurrence of 0.75 inch of precipitation in the form of rain and snow, the fire is declared controlled. (Another 1.25 inches fell the next day.) However, a number of ground fires are still burning, and an additional week of mopup is required before the fire is officially out.	Fire size 29,300 acres (11,857 ha.) Weather at 1300 [2] Wind--NE18 m.p.h. (NE8 m./sec.) Temp.--50° F. (10° C.), RH--100 percent Precipitation--0.75 inch

[1]Fuel types are listed in the table by descending amounts of acreage. GB-7 - grass--low brush, RB-10 - medium reeds--brush, R-14 - very high reeds; P-14 - high porosity, P-5 - low porosity--open.

[2]On-site reading.

[3]Intensity is defined as the rate of energy release per foot of fire front. Total intensity is defined as the total energy released per second by the fire during a given time period.

[4]Weather parameters estimated from readings at nearby weather stations.

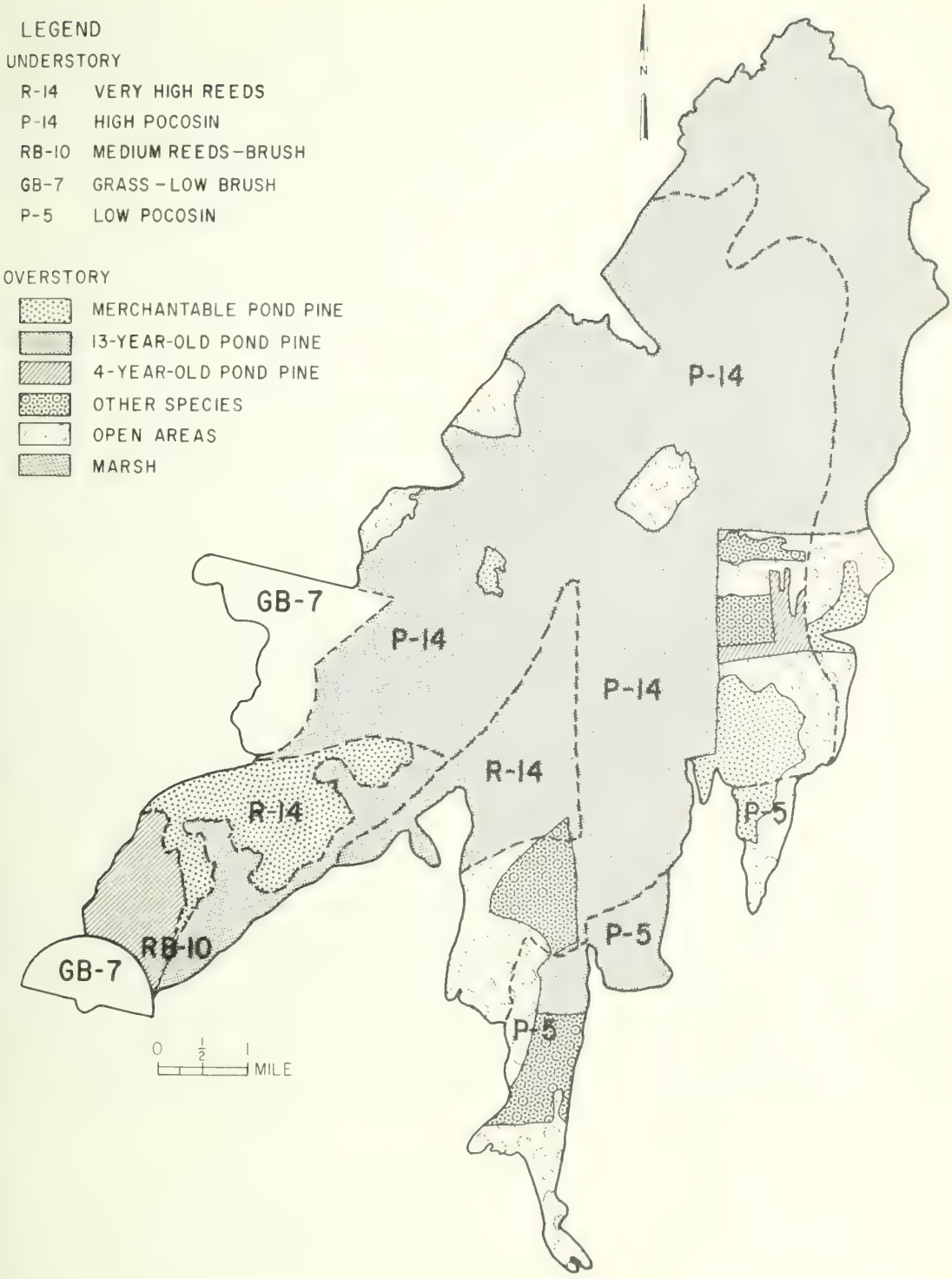

Figure 4.--Understory fuels and timber types on the burned area. [Understory map adapted from Wendel et al. (12). Overstory map adapted from: Honnold, Clark D. Damage appraisal, Westvaco Corporation lands, Dare County, North Carolina. 27 pp. 1971. (Appraisal rep., Appraisal contract DACA21-71-C-0071.)]

Table 2.--Weight, height, and blowup potential for five of the more common fuel types burned

Fuel type[1]	Fuel weight before burn[1,2]	Fuel weight after burn[3]	Blowup potential[1,4]	Average height of understory fuel
	lb./acre (kg./ha.)	lb./acre (kg./ha.)		ft. (m.)
P-14, high pocosin	25,600 (28,700)	2,000 (2,250)	3.4 (med. high)	14 (4.3)
R-14, very high reeds	30,900 (34,650)	2,100 (2,350)	5.8 (med. high)	10 (3.0)
RB-10, medium reeds--brush	21,900 (24,550)	2,100 (2,350)	2.8 (med.)	5 (1.5)
GB-7, grass--low brush	12,900 (14,450)	[5]500 (550)	1.1 (med. low)	3 (.9)
P-5, low pocosin--open	12,800 (14,350)	[5]2,000 (2,250)	1.1 (med. low)	2-3 (.6-.9)

[1] After Wendel et al. (12).

[2] Includes all understory vegetation, aerial and ground litter, and overstory needles.

[3] Estimated from a dozen $\frac{1}{4}$-milacre (1.01-m.^{2}) samples collected after the burn.

[4] Blowup potential for a given type of firebrand is the quotient of the ember lifting power of a fire in a fuel type of known weight per unit area and the ember lifting power of another fire burning in the same fuel type with the same heat yield and rate of spread but having a fuel weight of 6 tons/acre (13.5 M.T./ha.).

[5] Visual estimate.

Most pocosin shrubs are evergreen; their foliage and stems reach a minimum annual moisture content between 70 and 100 percent immediately prior to the initiation of new growth, which usually takes place in early April (2). The flammability of pocosin understory fuels was aptly summed up by Blackmarr and Flanner (2, p. 1), who stated that they form "... a dense, relatively homogeneous mixture of finely divided fuel particles suspended just above the litter." One of the striking features of the area was the large amount of needle drape providing vertical continuity of the fine fuel to the top of the overstory.

Fuels on the Air Force Bomb Range target area were classed as type GB-7 (grass--low brush) and weighed about 6 tons/acre (13.9 M.T./ha.). No overstory was present. Both NE and NW quadrants of the target area had been sprayed with herbicides during the summer of 1969. A prescribed burn was conducted on the area during the following winter, but the fire was of very low intensity and did not cover much of the area. Thus, most of the desiccated shrubs on these quadrants were still standing. Grass on the area was also very flammable because it was still in the cured stage.

WEATHER

Weather parameters for Dare County during March 1971 showed wide fluctuations. This is a typical situation and is due, in part, to the frequent passage of cold fronts over the area during this time of the year.

Precipitation was above the 30-year norm for March, and temperatures were a few degrees below the 30-year mean.[6] Four cold fronts

[6] Data taken from charts compiled by Environmental Data Service, NOAA, and published in Weatherwise 24(1-3), 1971.

moved across the area between March 7 and 25, but only 0.5 inch (1.3 cm.) of the 4.74 inches (12 cm.) of total rainfall during March at Elizabeth City--about 30 miles (48 km.) northwest of the fire site--fell during this period. The Drought Index (7) climbed from 0 in early March to 56 on the 25th, before again returning to 0 on the 29th. The Buildup Index (9) also reached its March maximum of 30 on the 25th.

A cold front moved rapidly across Dare County on March 19, bringing cold, dry air with it. Relative humidities, which were already low, continued to decline and remained below 60 percent for the next 72 hours, with daytime minima near 25 percent. Temperatures increased on the 22nd, reaching 70° F. (21° C.) on the bomb range by 1100 e.s.t.

The low relative humidities, high temperatures, and daytime windspeeds of 15 to 20 m.p.h. (7 to 9 m./sec.) all combined to create excellent drying conditions. On the day the fire began, the Buildup Index was 28, the Spread Index (9) was 36, and the Drought Index was 54. Periodic estimates of temperatures, relative humidities (RH), and wind velocities between March 22 and 26 are given in table 1.

Upper-air windspeed profiles at dawn and dusk on March 22 at Cape Hatteras--about 30 miles (48 km.) southeast of the fire site--both showed low-level windspeed maxima with decreasing windspeeds aloft for the next several thousand feet (900 to 1,200 m.) (fig. 5). These soundings were both classified according to Byram (3) as type 2-b. They were considered adverse from the standpoint of fire control because of the decrease in windspeed above the low-level maxima and the proximity of the maxima to the surface.

The data on temperature and relative humidity from the sounding taken at Cape Hatteras at 0615 e.s.t. are plotted in figure 6. If surface air on the bomb range at 1100 e.s.t. was displaced vertically, it would cool at the dry adiabatic lapse rate and rise to an altitude of about 7,400 ft. (2,200 m.) before coming to equilibrium with the surrounding air. The surface temperature of 70° F.(21° C.) at 1100 e.s.t. is marked by Point A on figure 6, and the line through this point depicts the temperature profile that would exist. The evening temperature profile (not shown) indicates that the afternoon mixing depth extended to nearly 9,000 ft. (2,740 m.).

Gusty surface winds were reported at the bomb range during the day, and pilots in the area experienced very bumpy flying--two strong indicators that vertical mixing was occurring in a layer near the ground. Because the atmospheric moisture represented by the tracing for relative humidity in figure 6 decreased rapidly through the first 2,600 ft. (800 m.) above the surface, vertical mixing would result in lower relative humidities near the surface. The sounding taken at Cape Hatteras at 1815 e.s.t. showed uniform relative humidities near 38 percent from 1,200 to 6,600 ft. (400 to 2,000 m.). This value is close to the average value of 36 percent for the 0615 sounding, indicating that vertical mixing in this layer did indeed occur during the day.

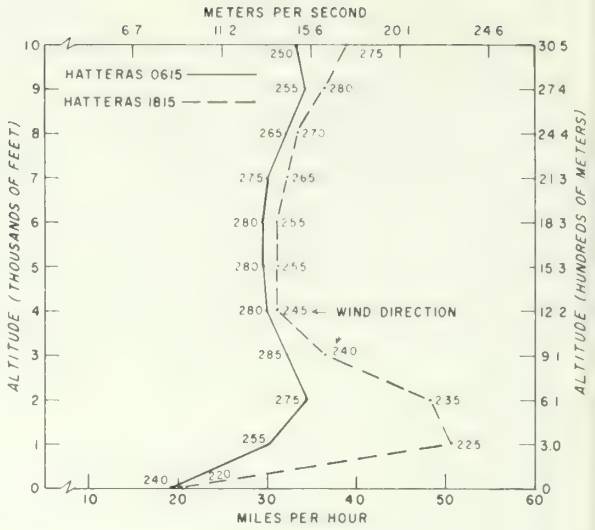

Figure 5.--Upper-air windspeed profiles at dawn and dusk of March 22, 1971, at Cape Hatteras. Wind direction is indicated by azimuth readings.

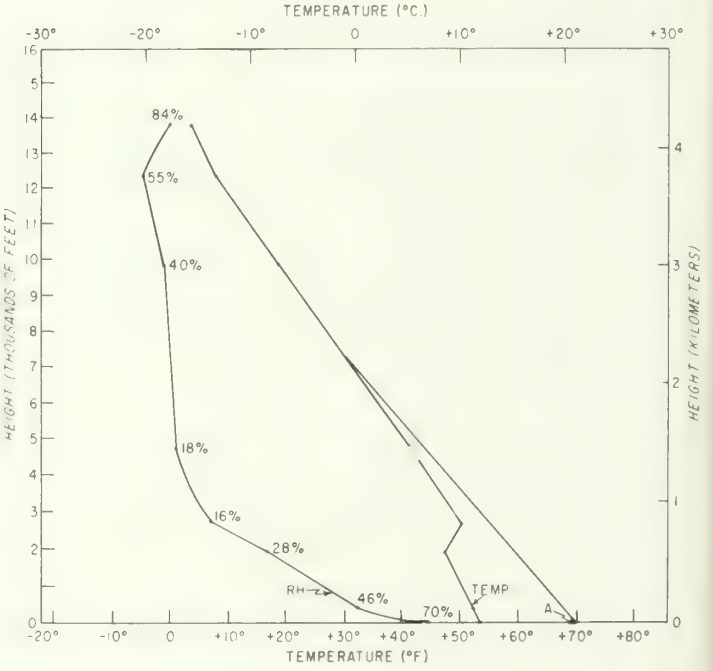

Figure 6.--Upper-air sounding taken at Cape Hatteras on March 22, 1971, at 0615 e.s.t. Point A indicates the surface temperature of 70° F. at 1100 e.s.t., and the line through this point depicts the temperature profile that would exist if the surface air was displaced vertically.

Surface winds backed from west to southwest during the day in response to changes in the surface pressure field associated with an approaching cold-frontal system. With the passage of the cold front at 0400 on the 23rd, the winds shifted to the north and drove the exposed flank of the fire south as a head fire. Scattered showers occurred ahead of the front, but rainfall was estimated to be less than 0.05 inch (0.1 cm.) and had little effect on the fire.

Winds remained northerly until the next cold front arrived over the fire 3 days later. This frontal system dumped over 1 inch (2.5 cm.) of rain and snow on the area, finally allowing fire control.

FIRE BEHAVIOR

Fire intensity (I) is defined as the rate of energy release per unit length of fire front. This rate depends upon such things as how fast the fire moves into new fuel, how much of the total fuel burns, how much energy is released when the fuel burns, and how fast the fuel is consumed (4).[7]

According to Wendel et al. (12), virtually all pocosin understory fuels are under 1 inch (2.5 cm.) in diameter. Field experience and laboratory tests indicate that most fuels under 1 inch (2.5 cm.) in diameter will be consumed within 4 minutes. Because of the short burnout time, all available fuel energy (heat yield) was considered released into the convection column. The amount of energy stored in pocosin fuels averages about 8,500 B.t.u./lb. (4,725 cal./g.) of fuel. An average moisture content of 70 percent was assumed for the fuel complex. The heat needed to vaporize the water in the fuel, the heat lost because of radiation, and the energy not freed because of incomplete combustion were all subtracted, resulting in an approximate heat yield of 5,000 B.t.u./lb. (2,780 cal./g.) of fuel consumed.

Calculated fire intensities per foot (cm.) of fire front, as well as rates of spread, fuel weights, and total fire intensities can be found in table 1. Rate of fuel consumption in tons/sec. can be derived for each time period by multiplying total fire intensity in B.t.u./sec. by 10^{-7}. Areas of major fuel types burned are listed by time period in table 3. These areas were used to calculate the average values for fire behavior during each time period given in table 1.

While the fire was still on the target area, computed fire intensity surpassed the 1,000 B.t.u./sec./ft. (8,260 cal./sec./cm.) value Byram (4) suggested as a maximum for the majority of wildfires. The air observer estimated the smoke plume to be 5,000 ft. (1,525 m.) high and building rapidly when the fire crossed Perimeter Road. Short-distance spotting was already occurring.

Upon entering the 4-year-old pine reproduction across Perimeter Road, the fire moved into the tree crowns. About 1,000 acres (405 ha.) of this dense, 6- to 8-ft.-tall (1.8- to 2.4-m.) reproduction were burned. The crown fire then continued toward Jackson Road through 1,350 acres (545 ha.) of older pond pine that had survived the 1957 fire; these pines were intermixed with 650 acres (260 ha.) of 13-year-old pond pine. Understory fuel type R-14 (very high reeds) was associated with the merchantable pond pine, and type RB-10 (medium reeds--brush) was associated with the remainder. Computed fire intensities ranged from 6,000 B.t.u./sec./ft. (49,560 cal./sec./cm.) in fuel type RB-10 to

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[7] $I = Hwr$

where: I = fire intensity, B.t.u./sec./ft. (cal./sec./cm.)
H = heat yield, B.t.u./lb. (cal./g.)
w = weight of available fuel, lb./ft.^{2} (g./cm.^{2})
r = rate of fire spread, ft./sec. (cm./sec.).

Table 3.--Areas of fuel types burned at specific times

Time (e.s.t.)	Location	Area burned in fuel type[1]--						Total area burned during time period	Cumulative area burned
		GB-7	RB-10	P-14	R-14	P-5	Marsh grass		
		acres (ha.)							
Monday, March 22, 1971									
1028	Fire origin	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1100	Center Road	8 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	8 (3)	8 (3)
1226	Perimeter Road	147 (59)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	147 (59)	155 (62)
1430	Jackson Road	49 (20)	1,139 (461)	0 (0)	751 (304)	0 (0)	0 (0)	1,939 (785)	2,094 (847)
1537	Navy Shell Road	146 (59)	235 (95)	345 (140)	155 (63)	0 (0)	0 (0)	881 (357)	2,975 (1,204)
1636	Highway 264	218 (88)	398 (161)	2,665 (1,079)	262 (106)	0 (0)	0 (0)	3,543 (1,434)	6,518 (2,638)
1745	NE of Highway 264	0 (0)	282 (114)	2,810 (1,137)	186 (75)	0 (0)	0 (0)	3,278 (1,326)	9,796 (3,964)
Tuesday, March 23, 1971									
0400	Flanking south	0 (0)	0 (0)	6,040 (2,445)	1,350 (546)	0 (0)	200 (81)	7,590 (3,072)	17,386 (7,036)
0600	Two heads south	0 (0)	0 (0)	3,640 (1,473)	648 (262)	1,880 (761)	0 (0)	6,168 (2,496)	23,554 (9,532)
Friday, March 26, 1971									
1000	End of fire	1,205 (488)	0 (0)	2,160 (873)	0 (0)	0 (0)	2,381 (964)	5,746 (2,325)	29,300 (11,857)
	Total	1,773 (717)	2,054 (831)	17,660 (7,147)	3,352 (1,356)	1,880 (761)	2,581 (1,045)		

[1]GB-7 = grass--low brush; RB-10 = medium reeds--brush; P-14 = high pocosin; R-14 = very high reeds; P-5 = low pocosin--open.

8,750 B.t.u./sec./ft. (72,275 cal./sec./cm.) in type R-14. We believe spotting increased in both intensity and distance until it began to exert a major influence on fire behavior and produced pulsations in the rate of energy release as the spot fires burned together. (This theory is discussed in depth in the section on patterns of fuel consumption.) The average rate of fuel consumption jumped from 0.18 ton/sec. (0.16 M.T./sec.) to 2.8 tons/sec. (2.5 M.T./sec.) as the fire burned toward Jackson Road.

The fire crossed Jackson Road at 1439 and moved into understory type P-14 (high pocosin) beneath a well-stocked stand of 13-year-old pond pine. This fuel type had the second highest blowup potential of any understory type on the burned area (table 2). However, the fire encountered a band of more mesic conditions between Jackson Road and Navy Shell Road, resulting in a decrease in fire intensity and a slight reduction in the average rate of fuel consumption to 2.7 tons/sec. (2.4 M.T./sec.). Only active flanking on the north side of the fire prevented a further decrease in the rate during this period.

The fire left this mesic area and ran into a much heavier quantity of fuel as it crossed Navy Shell Road. When the 1957 fire was burning in this same area, it was extinguished by showers southwest of Navy Shell Road, but no rain occurred northeast of the Road. Thus, the organic soil was consumed to depths of 1 ft. (0.3 m.) or more, creating an excellent seedbed northeast of the road. Southwest of the road, many of the existing pond pine rootstocks survived and sprouted, also creating a well-stocked stand, but it was less than one-half the density of the one northeast of the road. The understory was type P-14 (high pocosin) on both sides of Navy Shell Road, but it was noticeably more vigorous on the northeast side.

As the Air Force Bomb Range Fire crossed Navy Shell Road, the southwesterly surface winds pushed the exposed north flank into the heavier fuels. Thus, total fire intensity increased because of the greater amount of available fuel per unit area and the larger area of fire front. The convection column was rapidly pushed higher, and fuels such as pine cones and dead branches that had been acting as firebrands were ejected from the column at such heights that most of them burned out before landing.

Spotting density and patterns were difficult to observe because of the heavy smoke ahead of the fire. The air observers did report a multitude of firebrands in the convection column and a number of spot fires, but all were within one-half mile (0.8 km.) of the head. This spotting was partially responsible for the fire traveling the $4\frac{1}{2}$ miles (7.2 km.) to U. S. Highway 264 in less than 1 hour. Neither ground nor aerial observers noted any fire whirls on the fire.

An average intensity of over 18,000 B.t.u./sec./ft. (1.49×10^5 cal./sec./cm.) of fireline and a total energy release rate of 1.144×10^8 B.t.u./sec. (2.883×10^{10} cal./sec.) were calculated for this time

period.[8] The rate of fuel consumption reached 11.4 tons/sec. (10.3 M.T./sec.), its maximum value, and the fire more than doubled in size during this hour. The convection column extended to about 15,000 ft. (4,570 m.), where it was topped with a characteristic cap cloud.

After crossing Highway 264 at about 1635, the fire continued its run northeast, reaching Croatan Sound later that evening. The southwest winds driving the fire did not diminish that evening, and the fire flanked and crowned through more than 10,000 acres of pond pine, plantations of other coniferous species, and low, open pocosin during the night.

The cold front finally passed over the fire area about 0400 e.s.t., and the winds shifted to the north at 10 to 15 m.p.h. (4 to 7 m./sec.). Roughly 6 miles (9.7 km.) of flank became a head fire. Two main heads formed and ran parallel to each other, separated by Highway 264 which also runs in a north-south direction. The head east of Highway 264 tapered into a narrow prong and eventually stopped within 100 yards (90 m.) of the town of Stumpy Point. The fuel type changed from high pocosin under a pond pine overstory to a low pocosin with scattered pond pine about 2 miles (3.2 km.) north of Stumpy Point, and the area became progressively wetter until combustion could no longer be sustained.

The other head was bounded on the west by the band of very wet terrain that had slowed the fire the preceding afternoon and on the east by Highway 264. Intensity was calculated to be 4,427 B.t.u./sec./ft. (36,567 cal./sec./cm.) of fireline, and rate of fuel consumption was 8.7 tons/sec. (7.9 M.T./sec.). This head also ran into an open, marshy area the morning of the 23rd--bringing the period of major fire spread to a finish.

CONVECTION NUMBERS

High temperatures of the gases in and just above the flames make these gases lighter than the surrounding air. Because of their buoyancy, these gases rise and entrain cool air, which reacts with vaporized fuel to form additional combustion products. Thus, buoyancy is the driving force through which thermal energy of the fire is converted to kinetic energy of motion in the convection column.

Byram (4) has developed a theory for predicting the behavior of blowup fires on the basis of the ratio of the rate of conversion of thermal energy into kinetic energy in the smoke plume to the rate of flow of

[8]For comparison, the Sundance Fire, which burned over 50,000 acres (20,230 ha.) in northern Idaho in 9 hours, had a maximum calculated intensity of 22,500 B.t.u./sec./ft. (1.86×10^5 cal./sec./cm.) (1).

kinetic energy in the wind field. This ratio is called the convection number and is depicted by the symbol N_C.[9]

When N_C is greater than unity for a considerable height above the fire, the rate of energy conversion in the convection column surpasses the energy flow in the wind field. The fire will change from a forced convection system to a free convection system and may exhibit violent, unpredictable behavior. When the ratio falls well below unity, a smoke plume rather than a convection column exists and the energy flow in the wind field will dictate fire behavior. Analysis of numerous case histories of wildfires has led Byram (4) to the following observations:

1. N_C is usually greater than unity for a vertical distance of at least 1,000 ft. (300 m.) before a blowup fire can occur.

2. The condition most favorable to the sudden growth of the convection column occurs when N_C is greater than unity high above the fire. This condition is usually associated with a low-level windspeed maximum within 1,500 ft. (450 m.) of the surface.

3. Erratic fire behavior may occur in the transition zone as N_C approaches unity.

4. The vertical structure of the column is determined by the values of N_C rather than by the actual fire intensity and windspeed.

Several underlying assumptions must be made when using the convection number concept. The atmosphere should be neutrally stable, long-distance spotting should not affect rate of spread, released fuel energy should flow into a single convection column, and adequate data on fuels, weather, and fire behavior must be available. The absence of data concerning the vertical wind profile during the fire's run on Monday afternoon is the only major problem in using the N_C ratio on the Air Force Bomb Range Fire. Using morning and evening soundings from off-site stations to obtain results representative of afternoon conditions involves several risks. Recognizing the shortcomings of this procedure, we performed a straight-line interpolation of the dawn and dusk soundings on March 22 at Cape Hatteras to obtain a noontime windspeed profile.

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[9] $N_C = P_f/P_W$ where $P_f = I/C_p(T_o + 459)$ and $P_W = p(v-r)^3/2g$

where:
- N_C = convection number
- P_f = rate at which the buoyant gases of the convection column do work at any height z as they ascend above the fire, ft.-lb./sec./ft.^{2} (kg.-m./sec./m.^{2})
- P_W = rate of flow of kinetic energy in the wind field at height z above the fire, ft.-lb./sec./ft.^{2} (kg.-m./sec./m.^{2})
- I = fire intensity, B.t.u./sec./ft. (cal./sec./cm.)
- C_p = specific heat of air at constant pressure, B.t.u./lb./°F. (cal./kg./°C.)
- T_o = free-air temperature at the elevation of the fire, °F. (°C.)
- p = density of air at height z, lb./ft.^{3} (kg./m.^{3})
- v = windspeed at height z, ft./sec. (m./sec.)
- r = forward rate of spread of the fire, ft./sec. (m./sec.)
- g = gravitational acceleration, ft./sec./sec. (m./sec./sec.).

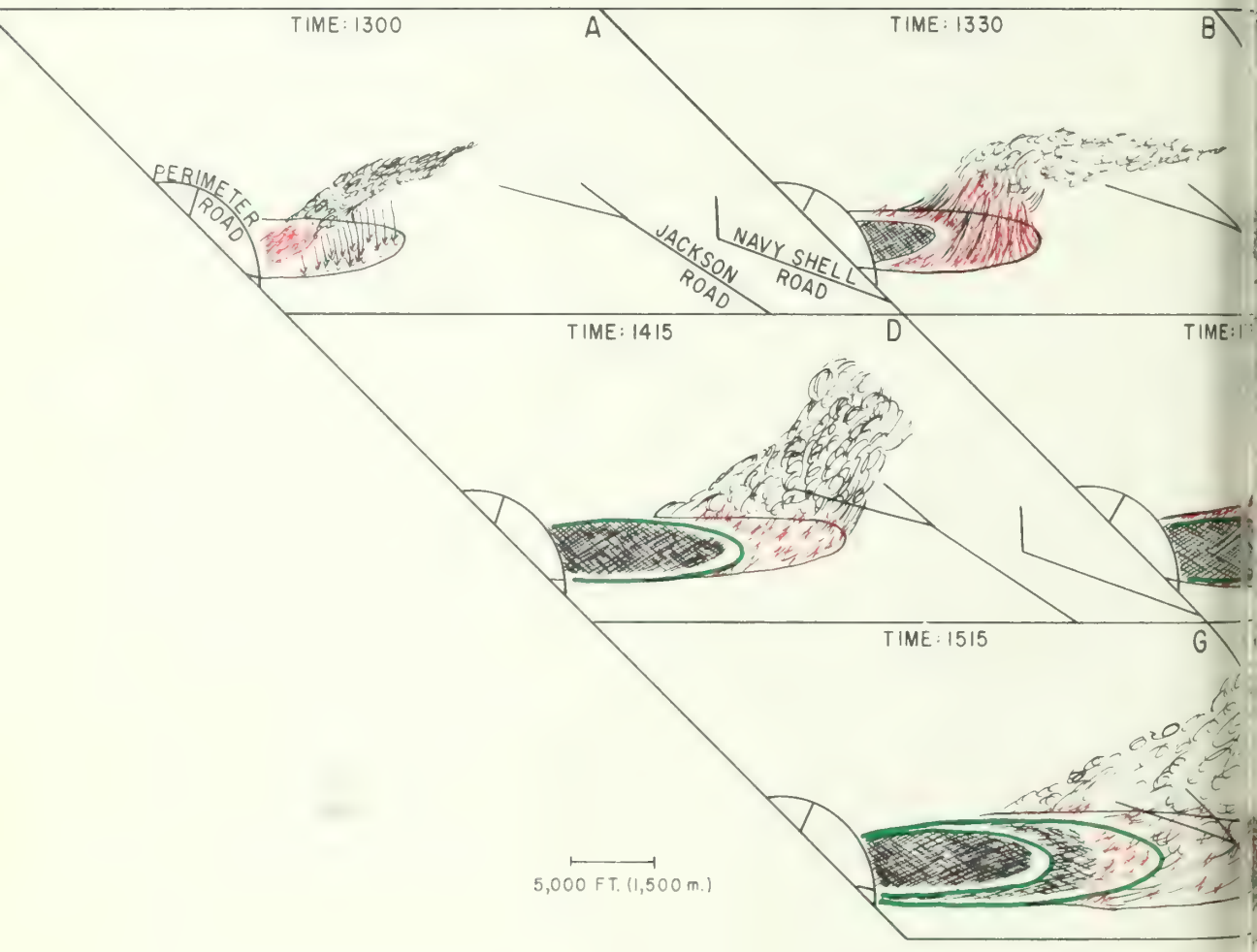
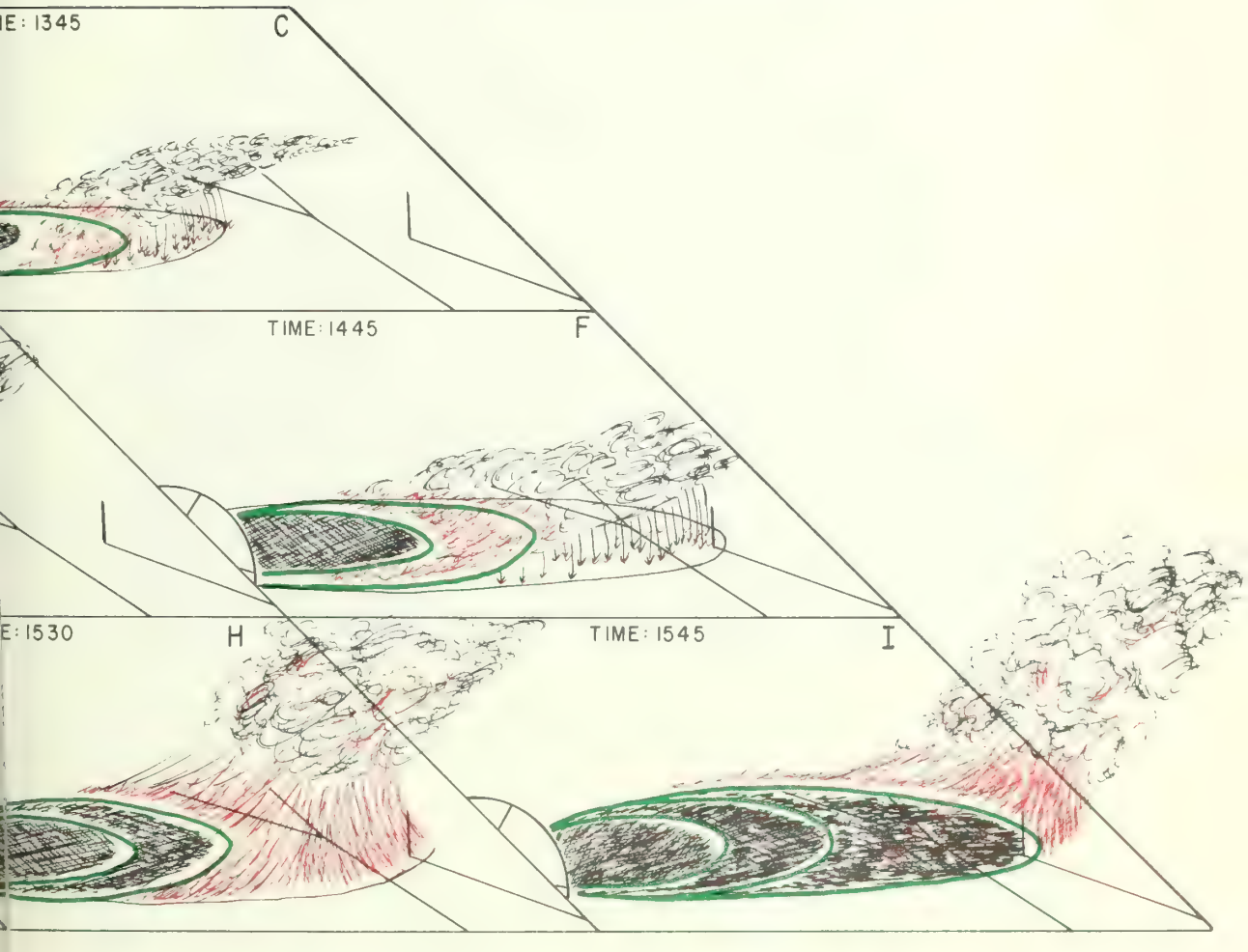

TIME: 1300
A
TIME: 1330
B
PERIMETER ROAD
JACKSON ROAD
NAVY SHELL ROAD
TIME: 1415
D
TIME: 1515
G
5,000 FT. (1,500 m.)

Figure 10.--Fire phenomena associated at various times with the formation of bands of unconsumed tree crowns as the fire progressed from Perimeter Road to Navy Shell Road. (See the text, page 23, for explanation of the drawings.)



Values of N_c at four time intervals on Monday afternoon were computed from the interpolated data on the wind profile (fig. 7). Actual N_c values fluctuated widely from the plotted averages because of pulsations in the rate of energy release. The times indicated in figure 7 are the approximate midpoints of the selected burning periods indicated in table 1. Reference to figure 7 and table 1 shows that the rise in surface N_c values paralleled the rise in fire intensity. Interpretation of figure 7 in conjunction with table 1 suggests the fire blew up when the N_c ratio increased to near unity. At 1610, N_c was greater than unity throughout an 8,000-ft. (2,400-m.) layer over the fire except at the low-level wind maximum. The fire had become 3-dimensional, as evidenced by the well-formed convection column that extended to about 15,000 ft. (4,500 m.) and a fuel consumption rate that exceeded 11 tons/sec. (10 M.T./sec.).

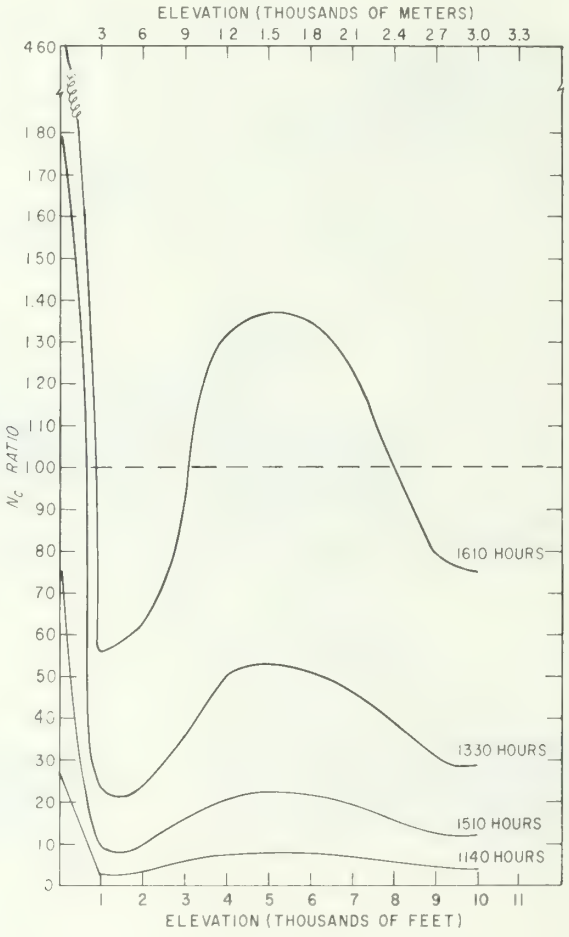


Figure 7.--Average N_c values at various heights and at four time intervals on Monday afternoon, March 22, 1971. Times indicated are the midpoints of selected periods from table 1.

PATTERNS OF FUEL CONSUMPTION

Fifty-ft.-wide (15-m.) bands of unconsumed tree crowns were formed about 1 hour apart. These are clearly shown in figure 3. The shape, spacing, and orientation of these bands are related to the fire's behavior, which, in turn, is a function of fuel, weather, and topographic

variables. The Exotic Dancer Fire[10] and the Air Force Bomb Range Fire are two fires in which consumption patterns were preserved in pocosin fuels (figures 3 and 8). Both fires were noted to burn cyclically. Surges in fire intensity were accompanied by changes in the physical appearance of the convection columns. The columns alternately leaned over and then stood more erect. Smoke color also alternated between yellow when the columns were tilted to black when they straightened.

Figure 8.--Fuel patterns preserved on the Exotic Dancer Fire, which burned 2,000 acres (800 ha.) in eastern North Carolina on May 23, 1970. (Photograph by the North Carolina Forest Service.)

On the Air Force Bomb Range Fire, several types of consumption patterns occurred, including pockets of unburned fuels and concentric rings of unconsumed tree crowns outlining various portions of the fire perimeter. Several theories have been proposed for the formation of such patterns. The following five hypotheses are listed because of their probable relevance to the observed patterns, especially to the three major bands outlining the fire perimeter at different times as the fire progressed from Perimeter Road to Navy Shell Road (figures 3 and 9):

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[10]Roten, Dane. Fire behavior study, Exotic Dancer Fire, Croatan National Forest. 38 pp. 1970. (Mimeogr. rep., N. C. For. Serv., Dep. Conserv. Dev.)

1. A fluctuation in wind direction for a few minutes could result in a decrease of fire intensity along one flank, with a probable increase in intensity along the opposite flank. This condition would result in the fire's backing under the tree crowns; then, as the wind resumed its original direction, active flanking and crowning would also resume. The lines of unburned fuel crossing Long Curve Road near its intersection with Navy Shell Road were probably caused by this sequence of events.

2. Windspeed could decrease below a level at which it would sustain a crown fire. If this period lasted for more than a few minutes before pre-lull windspeeds returned, the complete fire perimeter might be outlined as a result of fire spread through the surface fuels. Winds influencing the Air Force Bomb Range Fire were gusty, but winds remained above 10 m.p.h. (4 m./sec.) even between gusts.

3. The cyclic pulsations of several large fires in Japanese cities were analyzed by Yoshino (13). He found that (A) the first major run produced the greatest forward rate of spread; (B) after the initial run, lateral spread increased; (C) the accompanying decrease in forward velocity was inversely related to the initial rate of spread; (D) as burnout approached, the fires again became wind driven, achieving a second maximum rate of spread; (E) succeeding maxima in forward rate of spread were less than the initial maxima. The burnout time for wooden structures is much longer than the estimated 4 minutes for the fuels consumed in the Air Force Bomb Range Fire. Although the behavior of the latter was similar to that of the Japanese fires, the same self-regulating behavior cannot be applied to it because of this difference in burnout time.

4. Muraro speculated that pockets of unburned fuel might result from long-range spotting.[11] Ignition points in advance of the main front would tend to back toward the main fire front, as well as run with the wind--thereby forming pseudo-heads. As the main head approached the backfire, the intensity of the backfire and head would increase and the convection column would straighten as they joined. Burning embers would thus be raised faster and higher in the column, again producing long-range spotting. This mechanism could form pockets of unburned crown fuel, but the theory, although related to the behavior of the Air Force Bomb Range Fire, does not explain the observed formation of bands.

5. The unburned tree crowns outlining the entire fire perimeters of the Air Force Bomb Range and the Exotic Dancer Fires appear to be the result of the regulating mechanism that many high-intensity fires exhibit. The explanation we propose is based on the distribution of a large number of firebrands in a given pattern. The shape, spacing, and orientation of the drop pattern are functions of the height of the convection column and of the direction of the winds throughout the vertical distance through which firebrands must descend.

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[11]S. J. Muraro, Research Scientist, Can. For. Serv., Victoria, British Columbia. Personal communication, November 8, 1971.

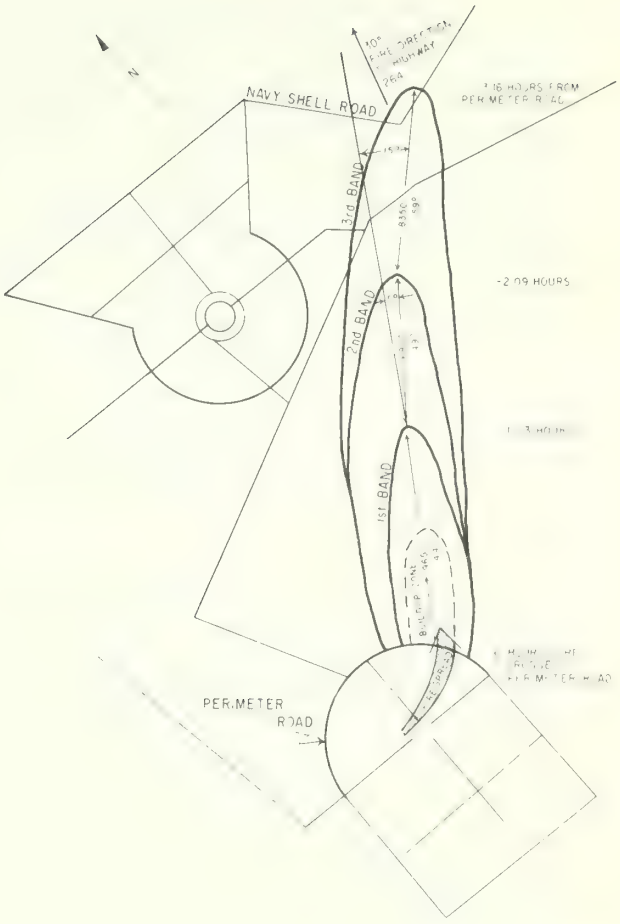

Figure 9.--Geometry of the three major bands of unconsumed fuel preserved as the fire progressed from Perimeter Road to Navy Shell Road.

Our hypothesis is supported by the cyclic, pulsating convection column that was observed to lean over and then stand erect. The spacing of the bands supports the idea that each succeeding pulsation was stronger than the last because of the larger area ignited. The orientation of the bands was to the right of the direction one would expect the fire to burn without long-distance spotting. Even young pond pines have large numbers of serotinous cones which make ideal firebrands. There was little other firebrand material available for long-distance spotting. If the concepts developed by Tarifa (10) are applied, it is reasonable to expect pond pine cones, when supported by the 35 m.p.h. (16 m./sec.) upper winds that existed over the fire, to carry fire as far as 7,000 ft. (2,100 m.) ahead of the main fire front. Greater distances would not be expected because the pine cones would probably burn out before landing.

The concept proposed here is that the Air Force Bomb Range Fire pulsated in a definite manner, as described and illustrated by the time drawings in figure 10 (see centerfold). According to the hypothesis, the first phase (fig. 10A) is marked by an increase in fire momentum, with an accompanying increase in spotting frequency and distance. Convective activity increases further, with a greater amount of spotting. No pronounced pattern of fuel consumption develops during this phase.

In the second phase (fig. 10B), the spot fires coalesce, with a higher rate of energy release. The convection column becomes well-developed, reaching an altitude of about 5,000 ft. (1,500 m.), and is loaded with pine cones which serve as potential firebrands. This strong convection column is maintained for 10 minutes at most because of the rapid burnout in the area. While the convection column is strong, the fire draws inward from all sides and the perimeter fire backs for a short time. Then, as the convection column dies down, the periphery of the fire picks up momentum as it burns under the crowns for a short distance, thereby leaving a nearly continuous band of unconsumed tree crowns.

In the third phase (fig. 10C), burnout occurs rapidly. The convection column loses its identity, and the firebrands are transported by the strong gradient winds. Those firebrands highest in the convection column are carried the greatest distance downwind and displaced the farthest to the right.

In the fourth phase (fig. 10D), the ignition points established during the previous phase begin to coalesce. The spot fires gradually increase in intensity as they become larger. As time progresses and individual spots act on one another, the rate of the rise in intensity accelerates.

In the fifth phase (fig. 10E), the second phase is repeated, with the convection column becoming stronger and reaching a greater height.

In the sixth phase (fig. 10F), the intensity decreases rapidly as available fuels are consumed. The column dissipates, emitting a shower of debris and firebrands downwind and to the right of the direction of the surface winds. As a result of the greater height of the column, the firebrands are distributed over a more extensive area lying farther to the right and stretching a greater distance downwind.

The seventh phase (fig. 10G) is a repetition of the fourth phase.

In the eighth phase (fig. 10H), a very strong convection column develops to a height of 8,000 to 10,000 ft. (2,400 to 3,000 m.). The band of unconsumed fuel created is oriented 10° south of the second band, 15° south of the first band, and may be as much as 30° from the direction of the surface winds (fig. 5).

In the ninth phase (fig. 10I), the convection column at first becomes weaker. However, it rapidly regains its structure as the open left flank is carried forward into the more abundant fuels on the north side of Navy Shell Road. The column is now sustained and reaches an estimated height of 15,000 ft. (4,600 m.) during the run to Highway 264.

The spacing and orientation of the bands of unconsumed tree crowns support the proposed hypothesis. The first band was created about 4,500 ft. (1,350 m.) in front of the head and had little, if any, displacement. The second band occurred 6,800 ft. (2,000 m.) from the first and

was displaced 5° to the right. The third band was some 8,300 ft. (2,500 m.) from the second and was displaced more than 15° from the first and more than 10° from the second (fig. 9). These displacements indicate that each surge of intensity resulted in the development of a stronger convection column that showered the area farther downwind and that each succeeding area was offset more to the right than was the area created during the previous pulse. Figure 5 shows how wind direction veered with height, causing the clockwise shift in the placement of the firebrands.

McArthur (8) has also observed fire pulsations resulting from mass spotting, but he does not mention consumption patterns. He suggests that pulsations in fire intensity occur as fuel moistures decrease toward the critical level during the day. During these pulsations, he suggests, the fire changes from a 2-dimensional to a 3-dimensional phenomenon for brief periods of time. Once this critical moisture level is passed, the fire remains 3-dimensional and no longer pulsates.

It is of interest at this point to return to the concept of the convection number (N_c), which is a method of comparing the rate the fire is doing work by thermal convection (P_f) with the work the winds are performing to overcome the thrust of the convection column (P_w). The intensity of the Air Force Bomb Range Fire conceivably fluctuated from 3,600 B.t.u./ft./sec. to over 18,900 B.t.u./ft./sec. (29,700 to 156,100 cal./cm./sec.) during the period when it progressed from Perimeter Road to Navy Shell Road (fig. 11). This hypothesis is based on the premise that the spot fires which were created after the convection column died down during any one cycle at first burned together slowly and that, during the last 10 minutes of the cycle, the fuels on 50 percent of the area were then consumed--thereby creating another strong convection column.

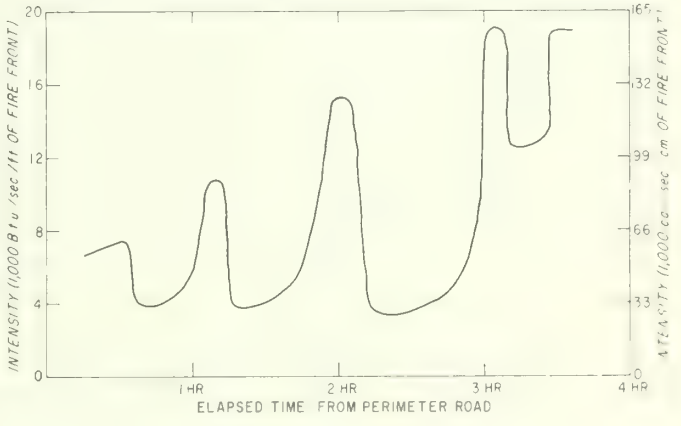

Figure 11.--Oscillations in fire intensity during the period when fuel bands were formed on Monday, March 22, after the fire crossed Perimeter Road.

In figure 12, the changes in N_c resulting from changes in intensity are plotted by height and isopleth lines are used to connect equal N_c values. This method illustrates the chance for growth of the convection

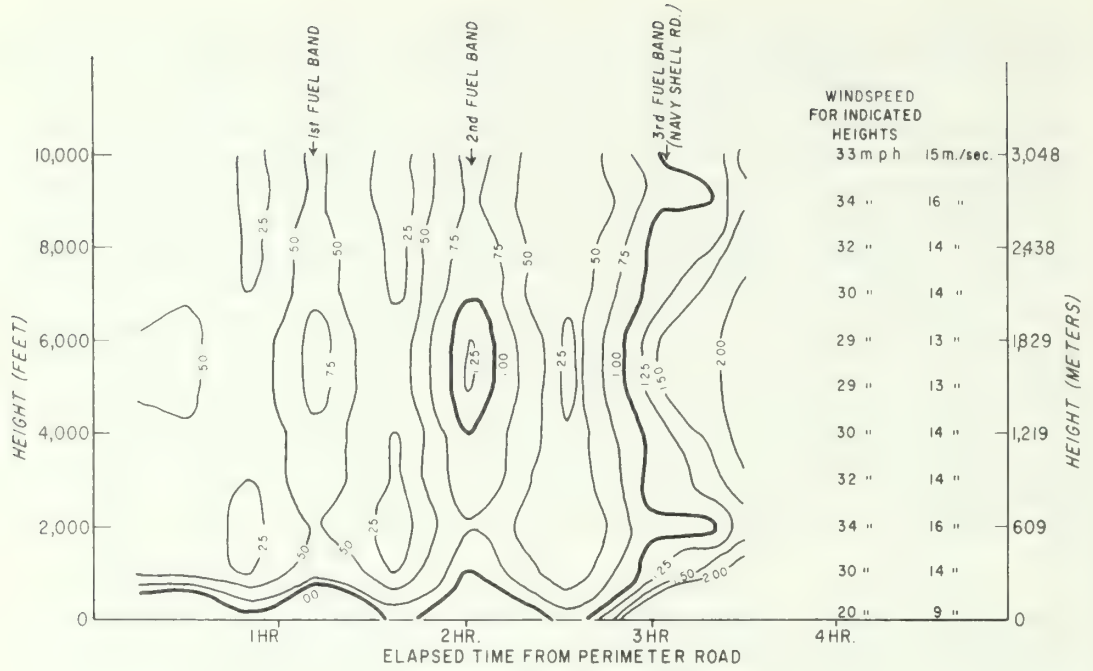

Figure 12.--Time-height cross section with isopleths connecting points of equal N_c value. These correspond to changes in fire intensity during the period when bands of unconsumed fuel were formed after the fire crossed Perimeter Road. An N_c value of 1 is depicted by the heavy isopleth lines.

column during the periods of surges in intensity. The convection column becomes most fully developed when N_c exceeds 1, which occurs when $P_f > P_w$. According to observations made at the fire site, P_f should have been greater than P_w for short periods prior to the time when the fire crossed Navy Shell Road and during the long run from Navy Shell Road to Highway 264. The 0615 sounding at Cape Hatteras (fig. 5) was used to calculate the values of N_c. It can be seen that, if the low-level windspeed maximum is reduced or the intensity of the fire is increased, N_c values will be increased. If, as might be expected, the lapse rate above the fire was actually super adiabatic because of neutral stability of the air, a parcel of rising air would pick up energy and the N_c ratio would increase. The windspeed profile Monday afternoon may have been different from the 0615 profile, but N_c values based on the 0615 profile serve to illustrate that band formation took place during peaks in fire intensity as expressed by the N_c values.

The patterns of fuel consumption exhibited by the Air Force Bomb Range Fire might occur in other areas as the result of changes in either fuels or topography. For example, a change in the vertical distribution of the fuel could obscure or destroy the patterns of fuel consumption resulting from changes in fire momentum. Homogeneous fuels, a large amount of fine fuel, a low fine fuel moisture content, and persistent weather appeared to be the critical factors associated with pulsations in both the Air Force Bomb Range and Exotic Dancer Fires.

Understanding the process of this band formation may make fire suppression more effective. Control techniques might be developed to take advantage of the time between peaks in fire intensity. There is a real danger, however, that a pulsating fire's development may be accelerated because of incorrect or poorly timed techniques of suppression firing. The effectiveness of the operation would depend on such things as the ability to accurately forecast periods of lower fire intensity as well as their durations and the areas where they would occur.

PARTICULATES AND VISIBILITY

The effect large wildfires such as the Air Force Bomb Range Fire have on visibility has not been adequately assessed. Increases in the background level of particulates on a global scale have been noted after large acreage losses during periods when numerous wildfires were burning. The effect large fires have on the reduction of visibility on a local scale can be pronounced. The effort here is to estimate the average concentration of particulates contained in a vertical cross section of the plume.

Because accurate emission factors are not available for wildfires burning in pocosin fuels, it was necessary to extrapolate laboratory findings from loblolly pine needles. In the laboratory, it was found that a slow-moving backfire produces about one-third as many particulates as a head fire. These data indicate that head fires produce about 60 lb. of particulates/ton (30 g./kg.) of fuel burned. A blowup wildfire, consuming immense quantities of fuel while producing strong indrafts and updrafts, probably entrains many times more particulates than the normal prescribed fire of low intensity. Those particulates larger than about 20 μ fall back to earth. Certainly, the larger particles in the form of limbs, pine cones, leaves, and needles fall rather quickly--probably within the first mile (1.6 km.). This fallout was documented by one of the North Carolina Forest Service pilots flying under the column at an elevation of 500 ft. (150 m.) about three-fourths mile (1.2 km.) in front of the fire. Extreme turbulence and peppering by miscellaneous debris were encountered as the plane flew under the column.

The efficiency of burning usually decreases as the rate of fuel consumption and resulting intensity increase. Laboratory studies of emission have substantiated this hypothesis. On the basis of this information, the factor of 60 lb. of particulates produced/ton (30 g./kg.) of fuel consumed was increased to 120 lb./ton (60 g./kg.) in order to more nearly conform with the fire situation at hand. During the time of the major run, the rate of fuel consumption increased abruptly to 11.5 tons/sec. (10.4 M.T./sec.). Under these conditions, the plume height about 3 miles (4.8 km.) downwind from the head was noted to be 15,000 ft.

(4,570 m.), with a lower limit of 1,000 ft. (305 m.). The plume was probably less than 7,000 ft. (2,133 m.) wide at this point. These inputs were used to calculate the average concentration of the smoke plume:

Area of plume cross section = (4,572 m. - 305 m.) x 2,133 m.

$$= 9.1 \times 10^6 \text{ m.}^2$$

Average windspeed of the vertical profile as based on the 1815 sounding at Cape Hatteras = 16.1 m./sec.

Ventilation factor = $(9.1 \times 10^6 \text{ m.}^2)$ (16.1 m./sec.)

$$= 1.46 \times 10^8 \text{ m.}^3/\text{sec.}$$

Particulate emission rate = (10,432 kg./sec.) (60 g./kg.)

$$= 626 \text{ kg./sec.}$$

$$= 6.26 \times 10^{11} \mu\text{g./sec.}$$

$$\text{Particulate concentration} = \frac{6.26 \times 10^{11} \mu\text{g./sec.}}{1.46 \times 10^8 \text{ m.}^3/\text{sec.}} = 4{,}260 \mu\text{g./m.}^3$$

Meteorological range may be a useful way of describing the net effect this concentration of particulates would have on visibility. Fritschen et al. (5, p. 21) define meteorological range as "... the visual range which would be observed if the air were perfectly homogeneous ...," that is, if the particulate size and shape were continuous throughout the plume. They used the following equation for computing meteorological range in smoke plumes:

$$\text{Meteorological range} = \frac{11.7 \times 10^5 \text{ km.}}{\text{Particulate concentration, } \mu\text{g./m.}^3}$$

If their equation is used, the meteorological range through a smoke plume with a particulate concentration of 4,260 μg./m.^{3} would be 275 m. or 900 ft. It is quite likely that the condensed water vapor and other products of combustion resulted in an even more limited visual range.

In a burn conducted to dispose of logging slash in the Pacific Northwest, Fritschen et al. (5) determined the maximum concentration of particulates 3.9 km. downwind and 0.9 to 1.6 km. in altitude to be 1,980 μg./m.^{3}. The rate of maximum energy release for their burn was about one-third the rate for the Air Force Bomb Range Fire. The average concentration of particulates 3 miles (4.8 km.) downwind from the Air Force Bomb Range Fire was at least twice the maximum concentration measured on the slash burn.

Visibility during the first 36 hours of the Air Force Bomb Range Fire was not reported to be a problem at ground level except for a 6-hour period at Cape Hatteras (fig. 1). Observers at the Cape noted a reduction in visibility to 3 miles (4.8 km.) Tuesday morning. On Tuesday, Wednesday, and Thursday nights, visibility became a severe problem along Highway 264. The problem stemmed from the combination of a low-level temperature inversion coupled with ground fires burning on the spill banks adjacent to the drainage ditches and canals. On Wednesday night, this inversion had trapped the smoke and fog in a layer roughly 5 ft. (1.5 m.) thick on the highway. Travelers driving cars through this layer of smoke and fog reported they could look out the side window and see stars above but not the roadway below. Persons walking more than 4 or 5 ft. (1 to 2 m.) ahead of these cars were completely obscured.

FIRE EFFECTS

The effect a high-intensity wildfire has on the vegetation, soils, and wildlife may appear much more severe immediately after the fire than at a later date. This generalization applies to the Air Force Bomb Range Fire. A survey of the burned area was conducted the week after the fire. In general, one would have thought a new barren had been created (fig. 13). There were carcasses of deer overrun by the fire and an obvious absence of small mammals. One wooden bridge spanning a 30-ft.-wide (9-m.) canal was destroyed along Navy Shell Road (fig. 14), and several others were saved only because of prompt action by control forces. Traffic along Highway 264 was snarled, and one accident resulted from the smoke. Luckily, ground conditions were wet and the fire stopped short of Stumpy Point.

Figure 13.--A dense stand of 13-year-old pond pine after the fire. Note the complete defoliation of the trees, consumption of the understory, and the high water table.

Figure 14.--Remains of a wooden bridge spanning a 30-ft.-wide (9-m.) canal along Navy Shell Road.

In general, pond pine and pocosin fuels have adapted well to a fire environment and usually return rapidly to pre-fire conditions after the occurrence of a wet-season fire. According to Garren's (6) classification of successional responses based on site conditions and fire frequency, one would expect little regeneration of pond pine and the creation of open areas after a dry-season fire. Neither the dry-season Dare County Fire in 1957 nor the wet-season Air Force Bomb Range Fire in 1971 followed Garren's fire successional patterns.

The Dare County Fire climaxed an extended period of drought. The fire burned for 2 weeks, consuming the organic soil to depths of 12 to 18 inches (30 to 46 cm.), thereby exposing, if not outright killing, many root systems of pond pine. Stumps remaining after the deep burning of the 1957 fire and the subsequent fire in 1971, which, in contrast, consumed little organic soil, are shown in figure 15. Comparison of the Drought Index at the time of each of these fires explains the differences in the consumption of organic soil (fig. 16). No sprouting occurred after the 1957 fire because the root systems were killed, but an excellent seedbed was created. Considerable rain also followed the fire and undoubtedly helped establish abundant regeneration of pond pine.

Pond pine sprouts readily from both the root collar and bole, and such sprouting was expected to occur after the Air Force Bomb Range Fire. Defoliation by wet-season fires generally has little effect on the survival of pond pine and causes only a temporary reduction in height and diameter growth. Dr. Maki[12] has noted that pond pine sprouts and

[12]Dr. T. E. Maki, Professor of Forestry, N. C. State Univ. at Raleigh. Personal communication, February 18, 1972.

Figure 15.--Stumps remaining after both the 1957 fire, which consumed the organic soil to depths of 12 to 18 inches (30 to 46 cm.) and exposed the root systems of the pond pine, and the Air Force Bomb Range Fire, which reburned the area but consumed little organic soil.

develops new boles from stumps less than 5 inches (13 cm.) in diameter and matures into commercial-sized trees of equal quality to those regenerated by seed. However, he has noted that, when stem diameter is larger, cambial strands from the root and bole seldom reunite.

Although no survival studies have been made for the Air Force Bomb Range Fire, the general impression upon viewing the area a year later was that a much lower percentage of trees sprouted from the bole than had been expected (fig. 17). The lack of bole sprouts is one more indicator of the high intensities associated with this fire. However, a high proportion of trees sprouted profusely from the root collar. The degree of basal sprouting suggests that a well-stocked stand of pond pine will again occupy the burned area, but the loss of 13 years' growth must be considered more than a temporary setback in a 50-year rotation.

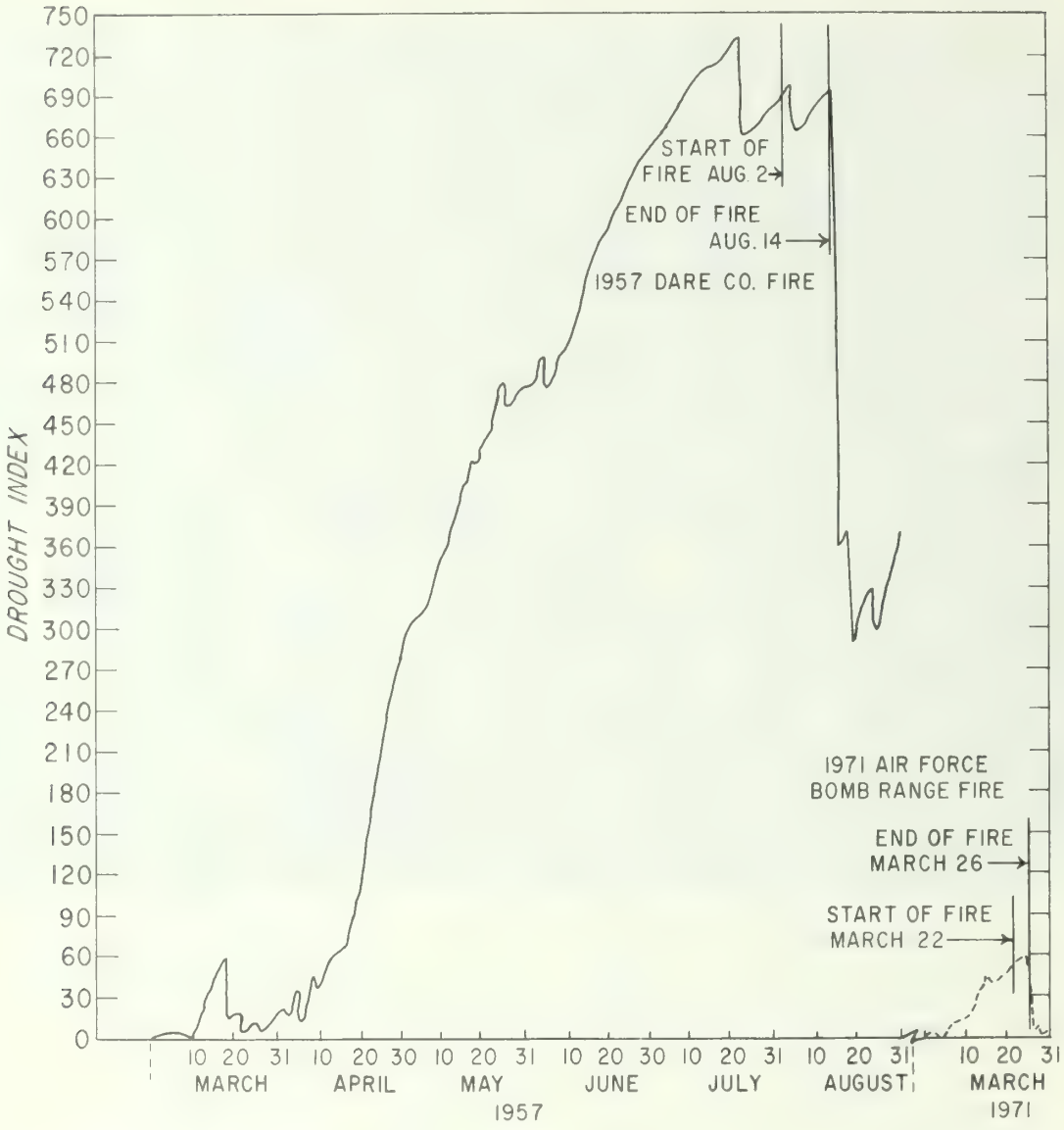

Figure 16.--Comparison of the 1957 and 1971 Drought Indices compiled from records at Elizabeth City, North Carolina.

The Army Corps of Engineers appraised the fire damage because of government liability. Clark D. Honnold,[13] the consulting appraiser, summed up the general condition of the burned area as follows: "From evidence on the ground throughout the entire fire-damaged area and including those plantations of pond pine which were hand planted or seeded, it is believed a stand at least similar to what was there before the fire will regenerate from sprouting or from seed from past seasons."

[13]Honnold, Clark D. Damage appraisal, Westvaco Corporation lands, Dare County, North Carolina, p. 4. 1971. (Appraisal rep., Appraisal contract DACA21-71-C-0071.)

Figure 17.--The burned area 1 year after the fire. Note the lack of bole sprouts, the prolific sprouting from the root collar, and the regrowth of the understory.

FIRE MANAGEMENT IN THE POCOSINS--RESEARCH NEEDS

In many respects, fire behavior in pocosin fuels remains a mystery. Facts have been slow to accumulate. Examples of unusual fire behavior are numerous. The Exotic Dancer Fire is one such example; it occurred on the Croatan National Forest some 75 miles southwest of the Air Force Bomb Range Fire. Another example of unpredictable fire behavior is described in the "Southern Region 1971 Annual Fire Report" (11, p. 15):

> "The Croatan had another high-intensity Pocosin fire on a low class day. BUI [Buildup Index] was 15 [and] SI [Site Index]-5, yet the fire burned 180 acres and ran three-quarters of a mile before being stopped. Had the fire started earlier in the day, or not met a road, it would have been much larger. We have

such limited knowledge of the Pocosin that we can offer no explanation. We can only guess that:

The actual fire conditions in the Pocosin are quite different from other areas.

Ratio of dead-to-live green fuels is deceptively high.

The pocosin fuels are always cured or in transition, never really green."

Our current fire danger rating system is not responsive to the fire potential of the pocosins. Research and development to adapt the national system to this area should have prime consideration. Beyond that, we need more information on the effects of fuel physics and chemistry on rate of burning.

The North Carolina Forest Service has made tremendous strides toward developing an effective capability of fire suppression. There is a need for continued research to determine the economics of fire suppression in the pocosins, to develop and apply advanced systems for delivering fire retardants during the day and at night, to improve methods of fire reconnaissance, to improve methods of suppression firing, to improve the accuracy of fire-weather forecasting, and to investigate the economics of fuel modification and the construction of fuel breaks.

Prescribed burning may be a solution to managing fuel buildups in the pocosins. Conditions and techniques under which accumulations of understory fuel can be reduced without damaging the pond pine overstory will need investigation. Finding the optimal approach to fire management in the pocosins will require looking into the periodicity of burning, alternatives to burning, fire protection, fire detection, and initial attack.

Case histories and documentations of fires have usually relied on human observations. In compiling such reports, these observations are checked one against another, compared with past observations, accepted or rejected, and modified where appropriate. Any single observation may offer but a small clue toward explaining the true picture of fire behavior.

Careful observations and measurements of fire parameters are needed. Equipment is already available for improving the researcher's ability to document fire behavior. Compact radiosonde units, aircraft-mounted infrared scanners, and portable stations for recording weather exist.

Fire modeling has not matured. Theories concerning convection columns, particularly those regarding entrainment of peripheral air, velocity cross sections, height of the column, dimensions of the column, the capacity to carry firebrands and particulate and gaseous contents, are fragmentary. Modeling experiments depend on the identification and measurement of critical parameters on site; only then can proper scaling be accomplished.

SUMMARY

The Air Force Bomb Range Fire started on a military bomb range in the pocosin area of eastern North Carolina and was not controlled until 4 days later. More than 23,000 acres (9,300 ha.) of the 29,300-acre (11,860-ha.) total burned during two major runs within the first 20 hours.

The fire crowned immediately upon entering a young forest of pond pine adjacent to the target area. Fire pulsations resulted in bands of unconsumed tree crowns that outlined the fire's perimeter during the first 5 miles (8 km.) of its run. After the fire crossed Navy Shell Road, its intensity increased and the convection column reached a height of about 15,000 ft. (4,570 m.) during the next hour while the fire traveled 4.5 miles (7.2 km.). Fire intensity during this 1-hour period averaged over 18,000 B.t.u./sec./ft. (148,680 cal./sec./cm.) of fireline, with a rate of total energy release of roughly 114 million B.t.u./sec. (2.883 × 10 cal./sec.). Fuel was consumed at a rate in excess of 11.4 tons/sec. (10.3 M.T./sec.). It was calculated that the fire produced 1,380 lb. of particulates/sec. (515 kg./sec.) during this run. Average concentration of the plume was about 4,000 $\mu g./m.^3$, with visibility in the plume considerably less than 1,000 ft. (300 m.). The fire front eventually ran out of dry fuel near Croatan Sound after traveling 14 miles (22.5 km.) in about 7 hours. Passage of a dry, cold front early the next morning resulted in a 6-mile (9.7-km.) run perpendicular to the first. This second run terminated within 100 yards (90 m.) of the town of Stumpy Point because of wet fuel.

Basically, the reasons for the fire's buildup were (A) a continuous expanse of homogeneous fuel, (B) abundant fine fuels--both live and dead, (C) low moisture content of both live and dead fuel, (D) 15 to 20 m.p.h. (7 to 9 m./sec.) winds gusting to 40 m.p.h. (18 m./sec.), (E) minimum relative humidity of 25 percent, (F) moderate-to-extreme turbulence, and (G) an adverse windspeed profile with a low-level windspeed maximum.

A theoretical parameter, N_C (the ratio of the energy in the convection column to the energy in the wind field above a fire at a given time), which was developed by Byram for predicting the potential for blowup fires, was applied to the Air Force Bomb Range Fire. It is hypothesized that, during the first 5 miles (8 km.), the buoyancy created by the fire was sufficient to override the gradient wind forces, allowing formation of a convection column for brief periods of time. During the 4.5-mile (7.2-km.) run after the fire crossed Navy Shell Road, N_C values were very large near the surface and greater than unity above the low-level windspeed maximum.

We have postulated that, after a run of less than 1 mile (1.6 km.) through the tree crowns, the fire spotted far enough ahead to allow a strong convection column to form as the spot fires coalesced. Because of the more westerly winds aloft, the firebrands in the convection column were ejected and transported to the right of the direction of the main fire. These spot fires coalesced with a higher intensity and stronger indrafts along the fire perimeter. This phenomenon resulted in the fire's

backing under the tree crowns for a short period of time. The cycle of spot fires forming to the right and then coalescing to form a strong convection column in which indrafts overrode prevailing winds occurred three times, and a 50-ft. (15-m.) band of unburned tree crowns outlining the fire perimeter was formed with each cycle.

Pond pine, especially trees smaller than 5 inches (12.7 cm.) in diameter, are well adapted to a fire environment. Even though more than 20,000 acres (9,000 ha.) of young pond pine were defoliated, it is probable that a stand of pond pine of equal quality will regenerate from basal sprouts.

A high water table during the Air Force Bomb Range Fire prevented the consumption of large quantities of organic soils but instead created other problems of fire control. The damp peat would not support the usual tractor-plow units, and final control of the fire was not achieved until over an inch of rain and snow fell on the area.

Until the behavior of blowup fires is understood, methods of controlling them will remain ineffective. The optimum role of fire in the management of pocosin fuels is unknown. As long as vast unbroken acreages containing abundant fine fuels exist in eastern North Carolina, the potential for frequent blowup wildfires will remain.

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CONVERSION FACTORS FOR ENGLISH AND METRIC SYSTEMS

1 inch (in.)	2.54 centimeters (cm.)
1 foot (ft.)	0.30 meter (m.)
1 mile	1.61 kilometers (km.)
1 mile per hour (m.p.h.)	0.45 meter per second (m./sec.)
1 acre	0.40 hectare (ha.)
1 milacre	4.05 square meters ($m.^2$)
10 stems per acre	25.00 stems per hectare (stems/ha.)
1 pound (lb.)	0.45 kilogram (kg.)
1 ton	0.91 metric ton (M.T.)
1 pound per acre (lb./acre)	1.12 kilograms per hectare (kg./ha.)
1 ton per acre (ton/acre)	2.24 metric tons per hectare (M.T./ha.)
1 pound per ton (lb./ton)	0.50 gram per kilogram (g./kg.)
1 British thermal unit (B.t.u.)	252.00 gram calories (cal.)
1 British thermal unit per pound (B.t.u./lb.)	0.56 calorie per gram (cal./g.)
1 British thermal unit per second per foot (B.t.u./sec./ft.)	8.26 calories per second per centimeter (cal./sec./cm.)

3-73

Wade, Dale D., and Ward, Darold E.
1973. An analysis of the Air Force Bomb Range Fire. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-105, 38 pp.

The Air Force Bomb Range Fire (March 22-26, 1971) crowned through 14 miles (22.5 km.) of pond pine in 7 hours and eventually burned 29,300 acres (11,860 ha.) of pocosin fuels in eastern North Carolina. Gusty winds, an adverse wind profile, passage of a cold front, and heavy, uniform loadings of fine fuel resulted in an unusually intense fire. Byram's equation for predicting fire blowup is utilized in the analysis. An hypothesis based on patterns of mass spotting resulting from a pulsating fire is presented to explain the formation of concentric bands of unconsumed fuel. Fire effects are discussed, and particulate concentrations and visibility are mentioned. Some thoughts on fire management in pocosin fuels are presented.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Fuel and Weather Influence Wildfires in Sand Pine Forests

by

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Fuel and Weather Influence Wildfires in Sand Pine Forests

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INTRODUCTION

Sand pine (Pinus clausa (Chapm.) Vasey) has a very limited range and, in general, low economic value. The largest concentration is a block of about 280,000 acres on the Ocala National Forest in north-central Florida (5, pp. 447-450); this block provides pulpwood for the local economy.

Sand pine is known as a fire species. The existence of even-aged, dense natural stands can usually be traced to large wildfires. The cones persist for years and open only when subjected to high temperatures. Because the trees often grow in dense stands, wildfires crown rather easily and spread rapidly. Estimated spread rates of 5 m.p.h. and higher have been reported (6).

Records of fires occurring from 1927 to 1952 in sand pine stands on the Ocala National Forest show that 80 percent of all wildfires larger than 10 acres in size occurred between February and June. Thirty-one percent of these fires occurred in the month of May (3). Rainfall deficiencies and dry fuel conditions can be as severe at other times of the year, but large fires occur only during the spring.

The ignitability and flammability of forest fuels are influenced primarily by fuel and weather conditions. The moisture content of green fuel is an important factor, and the influence of foliage moisture on crown fires has been mentioned by others (7, 12, 14).

The amount of inorganic material contained in plant tissue has been found to have an influence on the combustion process (10). Some components are inert and have little effect. Phosphorus, however, is one of the elements that can act as a retardant and show the burning rate of a fuel (2). Seasonal changes in phosphorus content, therefore, may have an effect on fuel flammability.

The material that can be extracted from pine needles with ether is insoluble in water and is composed of resins, waxes, oils, and fats. These materials have very high energy contents and, because they are easily vaporized, may be more available to combustion than are the non-extractable materials (11). If so, fuels with high amounts of such extractives may ignite easily (9) and burn intensely.

During the spring of the year, sand pine needles shine with exuded resinous material (referred to locally as "varnish"), which is suspected of being responsible for past conflagrations. A cooperative study between the Southern Forest Fire Laboratory and the Ocala National Forest was made in 1969-71 to evaluate the effect of fuel variables (including resin content) and weather factors on the occurrence of large fires in stands of sand pine.

METHODS

Wildfires

Fire records were summarized to show the acreage burned and the number of fires by months for each year in the period 1961-70. These data were supplied by the Ocala National Forest and include all sizes of fires occurring on the forest in the sand pine type. Only two fires exceeded 100 acres in size within this 10-year period.

Weather

Complete weather records were not available for Ocala, Florida; therefore, climatological data from Orlando, 35 miles south of the National Forest, were analyzed (13). The weather conditions on days when large wildfires occurred were obtained from surface observations made at Ocala airport and supplied by the National Weather Records Center.

Fuels

Samples of live sand pine needles were collected on the National Forest bimonthly between January and June and at monthly intervals from July to December in 1969 and 1970. Additional samples were collected at monthly intervals from January to June and also in October 1971.

These samples were separated into new and old needles in the field. New needles were from the branch tips and ranged in age from 0 to 10 months, whereas old needles were from the base of the branches and ranged from 9 to 18 months old. New needles initiated in April were probably included as part of the old sample in January of the next year. With several growth flushes in a single year, it was difficult to tell the exact age of the needles.

In 1969, needles were collected from the lower branches of trees about 25 to 30 feet tall in a naturally regenerated stand. In 1970 and 1971, trees in this stand were again sampled, as were younger trees 10 to 15 feet tall from a plantation about 1 mile away.

All samples were mailed to the Southern Forest Fire Laboratory, ovendried at 85° C., and ground in a Wiley mill. Moisture and energy contents and amount of benzene-alcohol extractives were measured for all samples. The samples collected in 1969 were subjected to ignition tests in a muffle furnace at 232° C. Those collected in 1971 were tested for amounts of ether extractives and inorganic elements (including P, Ca, K, Mg, Mn, Al, and Na).

RESULTS

Weather and Wildfires

The variations in the number of fires and acreage burned from 1961 through 1970 were correlated, in a general way, with average monthly precipitation for the same period (fig. 1). The relationship was strongest in spring and summer and weakest in the fall. Although a small secondary peak in number of fires did coincide with the low amounts of precipitation in the fall, it is apparent that very little acreage is lost in the normally dry months of October through January. This small acreage loss is explained in part by less severe fire weather: fewer days with low humidities (40 percent or less) and high windspeeds (9 m.p.h. or more) occur during these months. Also, airmasses are generally more stable in the fall and winter.

The fire data also showed that fire occurrence may be relatively high in a month with normal or high rainfall if there are periods of 4 to 7 days between rains. Light, fine ground fuels dry in this length of time and will ignite; however, the fires spread slowly and are easily controlled. Heavy rains of short duration do little to restore fuel moisture that has been lowered by drought (4). The excess water will run off the fuel and quickly drain through the sandy soils. Thus, heavy but infrequent showers will not reduce the fire hazard for long.

Weather conditions associated with three large fires in the sand pine type were compared. The fires occurred on February 19, 1950 (200 acres), on March 29, 1962 (285 acres), and on April 18, 1970 (130 acres). There seemed to be a general weather pattern associated with these fires:

(1) Rainfall deficiencies occurred during the fall before the fire and continued into the spring fire season. For example, rainfall was 6.0 inches below normal from September through December 1961 and 1.8 inches below normal from January through March 1962.

(2) On the days when large fires occurred, relative humidity tended to be low (23 to 35 percent) and windspeeds high (9 to 20 m.p.h.). Visibility was very good (12 to 15 miles), indicating frontal passage or an unstable airmass.

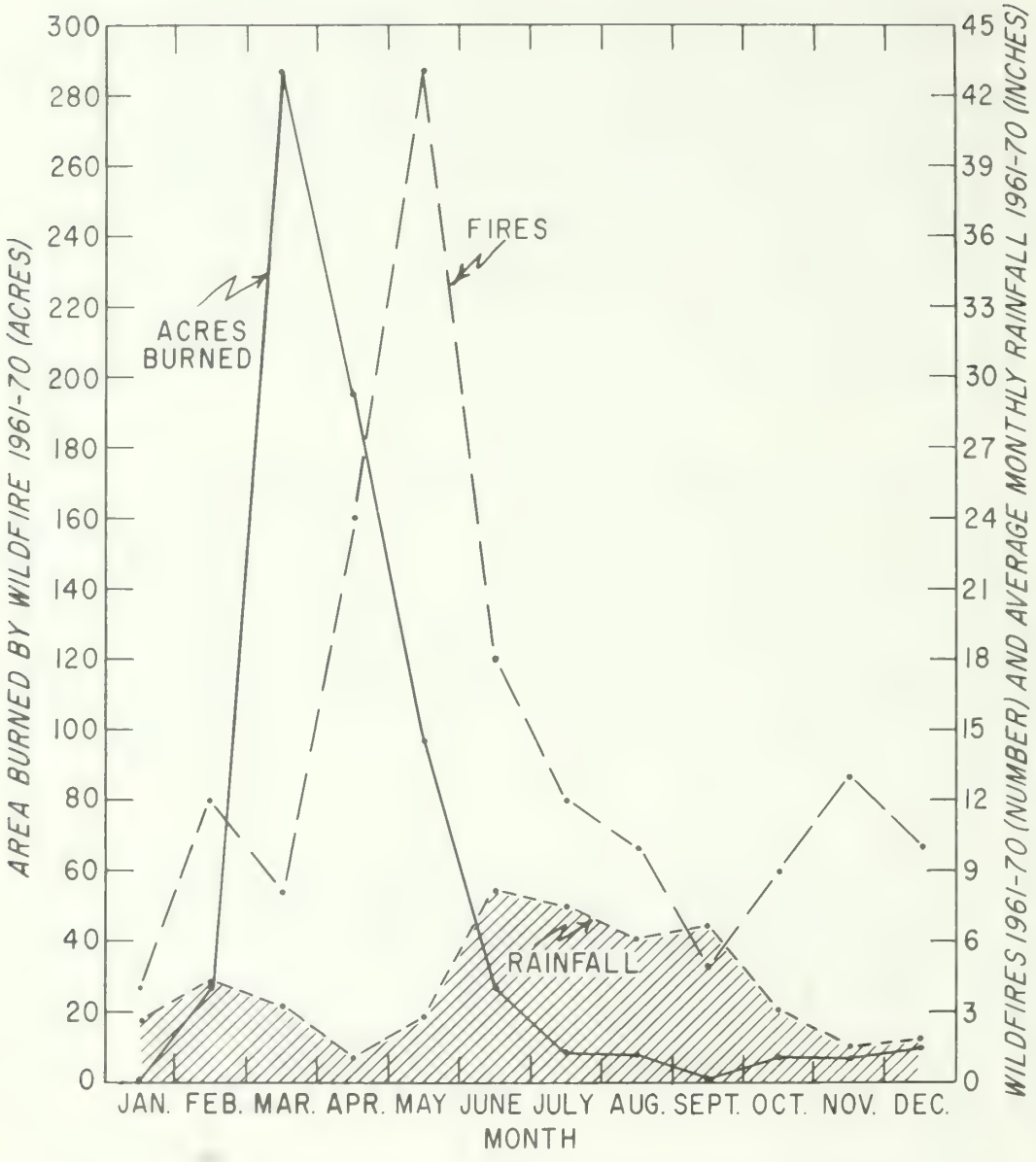
AREA BURNED BY WILDFIRE 1961-70 (ACRES)
WILDFIRES 1961-70 (NUMBER) AND AVERAGE MONTHLY RAINFALL 1961-70 (INCHES)
ACRES BURNED
FIRES
RAINFALL
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
MONTH

Figure 1.--Total number of wildfires and acreage burned each month in sand pine stands on the Ocala National Forest and average monthly rainfall at Orlando, Florida, from 1961 through 1970.

Fuels and Wildfires

None of the fuel characteristics measured during this study could be used by itself to predict the occurrence of a large wildfire in sand pine stands. Three variables did, however, exhibit annual trends that help account for the occasional spring conflagration:

(1) Moisture content.--A low point in the seasonal variation in moisture content of new and old needles occurred in March (fig. 2). Moisture content of old needles increased through the summer and

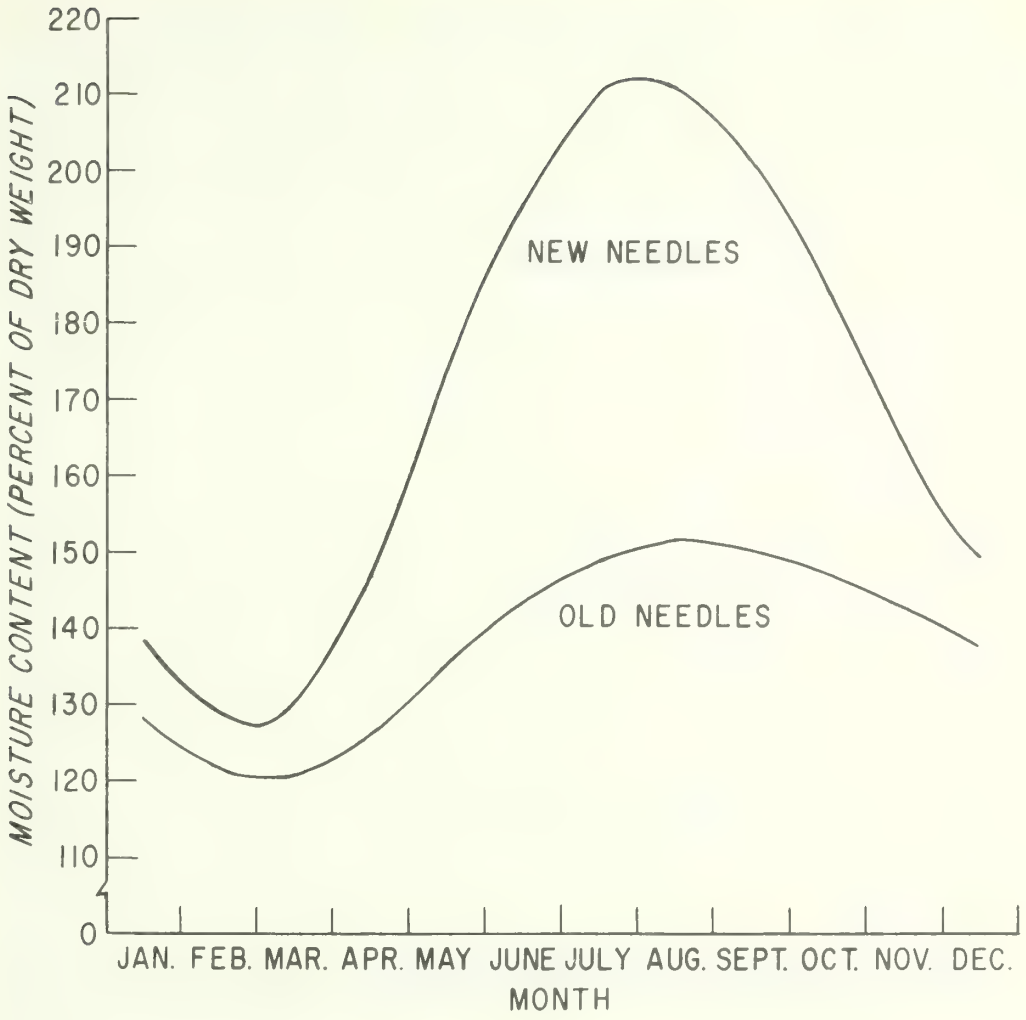

Figure 2.--Seasonal variation in moisture content of new and old needles (smoothed curve through data points for both areas and all years) and phenology of sand pine trees: (Jan.) flowers are developed and vegetative buds swell; (Feb.) buds break dormancy; (Mar.) shoots elongate; (Apr.) at the beginning of the month shoots are 1 to 2 inches long and needles are visible; by the end of the month shoots are 3 to 6 inches long and needles are $\frac{1}{4}$ to $\frac{1}{2}$ inch long; (May) shoots are 6 to 8 inches long and needles are $\frac{1}{2}$ to 1 inch long; by the end of the month, new vegetative buds are formed; (June) needles are 1 to $1\frac{1}{2}$ inches long and another growth flush develops; (July) needles are $1\frac{1}{2}$ to 2 inches long; by the end of the month, some old needles are yellowing; (Aug.) needles approach full size; (Sept.) main needle fall begins; (Oct.) another growth flush begins; (Nov.) April needles reach full size; (Dec.) vegetative buds change color and flower buds start growth.

reached its highest values in August and September. Moisture content of new needles rose sharply to very high values in June and July and decreased through the rest of the year. These high values resulted from initiation of new growth.

(2) Ether extractives. --The content of ether extractives in old needles was at a very high level throughout the year and rose to a slight peak in March (fig. 3). The content of ether extractives in new needles also reached a peak in March, then dropped sharply as the spring growth flush occurred, and reached a low in June. The extractive content rose through the rest of the year as the new needles matured, but the values remained consistently lower than those found in old needles. Seasonal trends similar to the curves for extractive content were also evident in energy content of sand pine needles. This similarity was not surprising because heat value and extractive content of these needles were found to be directly related. Ether extractives and energy values for sand pine are generally higher than those for most other pines, and they compare with the high values reported for California brush species (9).

(3) Phosphorus content. --The phosphorus contents of new and old needles were about the same at the start of the year, and both decreased until March (fig. 3). Old needles continued to lose phosphorus until June, but their phosphorus content then increased through the rest of the year. As shoots elongated and needle growth began, phosphorus content increased sharply in new needles, reaching a peak in April. Phosphorus in new needles decreased through the summer months but remained higher than the content of old needles. Similar changes in phosphorus content have been reported for loblolly pine (16).

Benzene-alcohol extractives were not strongly correlated with trends in fire occurrence or acreage burned. The alcohol fraction extracted sugars and other readily soluble compounds from the live material; this fraction confounded the results by masking the changes in resin content.

Results of tests in the muffle furnace were variable but indicated that old needles ignited much more frequently than new needles. These tests also showed that no ignition occurred in any of the new needles collected between mid-May and August, the period during which needles had high moisture and phosphorus contents and low ether extractives.

DISCUSSION

The variation in acreage burned cannot be fully explained by weather factors, indicating that fuels also have an influence on the behavior of crown fires in sand pine stands. The seasonal trends in the fuel characteristics followed in this study indicate that crown fires have the highest probability of occurring in late February or early March. This is the period during which both new and old needles have the lowest moisture and the highest ether extractive contents. Phosphorus content of new needles is also lowest at this time, whereas phosphorus content of old needles is low but not at its minimum value until June.

Although fuels would have their greatest influence on crown fire at this time, it must be remembered that the major portion of the tree crown will remain highly flammable through May or June. It is not until the new needles make up a significant part of the total crown that

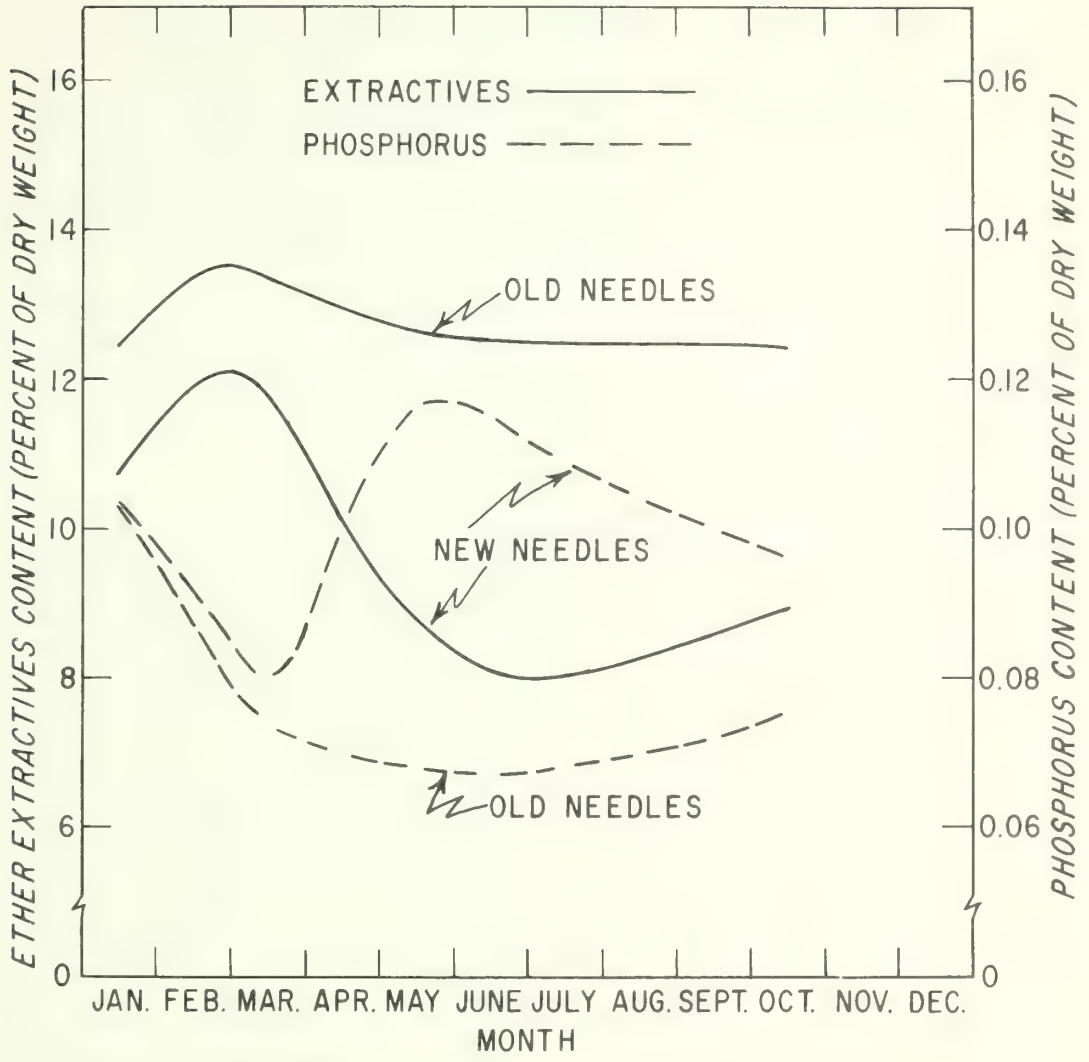

Figure 3.--Seasonal variation in content of ether extractives and phosphorus in new and old needles of sand pine (smoothed curves through data points for both areas in 1971).

their high moisture content and low extractive content will influence fire behavior.

The occurrence of maximum or minimum values in these fuel factors coincides closely with the break in bud dormancy and the start of shoot elongation (fig. 2). Low moisture content of older needles at this time of the year has been reported in many other species (1, 8, 14) and appears fairly typical of the pines. At the time of shoot elongation, moisture and phosphorus may be translocated from the older plant parts to the active growth centers to satisfy the requirements of the developing tissue. This is an important factor in drought years because soil moisture is not readily available and there is a greater demand on the older needles. Thus, the moisture in old needles may be even lower, resulting in easier ignition and faster spread of crown fires.

Crowning in sand pine takes place after the start of a surface fire. Normally, ignition occurs in the litter layer or cured vegetation and is influenced primarily by the moisture content of the dead fuel. The number of fires, therefore, depends upon the number of ignition sources (risk) and the relative humidity. The energy released as the dead fuels burn may involve the understory vegetation, which may then carry the fire into the tree crowns. Obviously, young stands with low branches increase the chance that the surface fire will reach the crowns. In older stands, the understory vegetation would play a major role in getting the fire into the overstory. It is reasonable to assume that understory plants also have cycles in moisture, mineral, and extractive contents. Preliminary tests show these fuels have trends similar to those in sand pine crowns, reinforcing the fact that spring fires are likely to be more intense than fall fires.

Most crown fires are supported by the surface fire and cannot advance ahead of it (15). In dense stands of sand pine, crown fires can burn independently once flame from the surface fire ignites the tree crowns. The forward progress of the crown fire is controlled by the very delicate balance between fuel arrangement, windspeed, energy release, and energy transfer. If crowns are widely spaced or windspeed drops below 4 or 5 m.p.h., the fire will not crown because of the reduced amount of energy transferred to the unburned fuels. If moisture content of the foliage is high, combustion efficiency is reduced and greater amounts of energy are required to bring the needles to ignition temperatures. This is undoubtedly the reason for less crowning in the fall when needle moisture is high. The effectiveness of aerial water drops in knocking down the head of crown fires in sand pine stands is a simple matter of adding water to the surface of the needles, thereby decreasing their flammability. Water drops that were allowed to dry for 24 hours had no effect on the spread of crown fires (6).

The influence of windspeed on the spread of crown fires through sand pine was observed on small test fires conducted in May 1964 and May 1965 on the Ocala National Forest. Winds in 1964 were steady in speed and direction, and hot crown fires developed. In 1965, fuels were much dryer but winds were weak and variable in direction. Fires crowned only in spots and then dropped back into the understory fuel.

CONCLUSIONS

The results of this study indicate that both weather and fuel variables have an influence on the occurrence of large fires (over 100 acres) in sand pine forests. The weather and fuel factors that influence fire behavior reach critical levels in the spring of the year. Moisture content of the needles was found to be the most important fuel variable, and the appearance of new shoot growth can be used as an indicator of the start of the critical fire period. Fuel variables become important, however, only when accompanied by certain weather patterns. Weather conditions associated with large fires during the spring include

(1) Extended deficiencies of rainfall over several months (especially the fall and winter before a spring fire season)

(2) Frontal movement through the area (especially if associated with low humidities and high winds)

(3) Low-level instability (0 to 5,000 feet) of the airmass (especially if absolutely unstable conditions prevail).

These are indicators of increased potential for the development of large fires and erratic fire behavior, and control agencies should be alert to their occurrence.

ACKNOWLEDGMENT

The author wishes to acknowledge the cooperation and assistance given by personnel of the Ocala National Forest, especially Kie Vining, Jr., Fire Control Officer, for collecting samples and summarizing the fire data.

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Hough, W. A.
1973. Fuel and weather influence wildfires in sand pine forests. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-106, 11 pp.

A complex combination of fuel and weather factors accounts for the dangerous fires that often develop during the spring in sand pine forests of Florida. Moisture content of live needles is lowest in March, and resin and energy contents reach their yearly highs during the 4-month period from February through May. These fuel properties become critical, however, only when they are accompanied by rainfall deficiencies that begin in the fall and winter and continue through the spring and by unstable airmasses with low relative humidities and high winds.

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SDA Forest Service Research Paper SE-107 May 1973

Volume and Weight Tables for Plantation-Grown Sycamore

by

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Volume and Weight Tables for Plantation-Grown Sycamore

by

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Athens, Georgia

American sycamore (Platanus occidentalis L.) is well suited for short-rotation management. It can be regenerated easily, has produced excellent early growth on good sites, and lends itself to mechanized harvesting. Steinbeck et al.[1] concluded that spacings of 4 by 4 feet or more and rotation ages from 4 to 10 years hold considerable promise from the standpoints of production, utilization, and management. This paper presents cubic-foot volumes, green weights, and dry weights for the tree sizes expected under these conditions.

DATA COLLECTION

Measurement data were collected from an 11-year-old sycamore plantation located on a well-drained Piedmont river bottom in Greene County, Georgia (fig. 1). The 4-acre planting site was disk plowed and then hand-planted with 1-0 seedlings spaced 8 by 8 feet during the winter of 1960-61. The seedlings were cultivated and fertilized during the first growing season and then thinned and fertilized again in 1968. The entire plantation was harvested after leaf fall in November 1971.

Measurements were taken on 103 sample trees randomly selected from 4- to 10-inch diameter classes. Data collected on each tree included

1. Diameter at breast height (d.b.h.)
2. Diameter outside bark at 5-foot intervals up the tree
3. Merchantable height (top diameter of 3 inches outside bark)
4. Total tree height

[1]Steinbeck, Klaus, McAlpine, Robert G., and May, Jack T. Short rotation culture of sycamore: a status report. J. For. 70: 210-213. 1972.

Figure 1.--Eleven-year-old sycamore plantation in Greene County, Georgia. Average d.b.h. in the plantation was 5.8 inches; average height was 63 feet.

5. Green weight (including bark) of each 5-foot bolt to the 3-inch top

6. Green weight (without branches) of the top

7. Green weight (without leaves) of the live branches.

A subsample of 31 trees was selected for more intensive measurements. These data included

8. Green weight of individual sample disks, 1 to $1\frac{1}{2}$ inches in thickness, taken from the base of the tree, at successive 10-foot intervals up the merchantable stem and at the 3-inch top diameter

9. Green weight of disks taken at 5-foot intervals up the remaining top stem

10. Combined green weight of branch disks, taken randomly from the lower, middle, and upper crown

11. Ovendry weights of the disks from the stem, top, and branches.

EQUATIONS

Cubic Foot

Cubic-foot volume (V) was calculated for each bolt from Smalian's formula

$$V = \frac{B + b}{2} L \qquad (1)$$

where B equals the area of the lower base in square feet, b equals the area of the upper base in square feet, and L equals the length of the bolt in feet. Volume of the top portion was computed from the formula

$$V = \frac{BL}{3} \qquad (2)$$

Volumes of the merchantable stem and total stem were calculated for each tree. Standard linear regression procedures were used to compute the following prediction equation for merchantable stem volumes:

$$\text{Merchantable stem volume (3-inch top outside bark)} = -0.34456 + 0.00246(D^2H) \qquad (3)$$

A constrained regression (intercept = 0) was used to develop the following equation for total stem:

$$\text{Total stem volume} = 0.00252(D^2H) \qquad (4)$$

For both equations, D is diameter at breast height in inches and H is total tree height. Variation explained by the constrained regression was computed from the formula

$$\frac{b\Sigma XY - \frac{(\Sigma Y)^2}{n}}{\Sigma (Y-\bar{Y})^2} \qquad (5)$$

where b is the regression coefficient for slope, X is D^2H, Y is cubic-foot volume, and n is the number of trees in the sample. Equations (3) and (4) account for at least 98 percent of the variation in observed cubic-foot volume. Predicted values for a combination of diameters and heights are given in tables 1 and 2.

Table 1.--Cubic-foot volume (outside bark) to a 3-inch top diameter[1]

D.b.h. (inches)	Total height (feet)							
	45	50	55	60	65	70	75	80
	Cubic feet							
4	1.4	1.6	1.8	2.0	2.2			
5	2.4	2.7	3.0	3.3	3.7	4.0		
6		4.1	4.5	5.0	5.4	5.9	6.3	
7			6.3	6.9	7.5	8.1	8.7	
8			8.3	9.1	9.9	10.7	11.5	12.3
9				11.6	12.6	13.6	14.6	15.6
10					15.6	16.9	18.1	19.3

[1]Block indicates extent of observed data.

Table 2.--Cubic-foot volume (outside bark) of total stem[1]

D.b.h. (inches)	Total height (feet)							
	45	50	55	60	65	70	75	80
	Cubic feet							
4	1.8	2.0	2.2	2.4	2.6			
5	2.8	3.2	3.5	3.8	4.1	4.4		
6		4.5	5.0	5.4	5.9	6.4	6.8	
7			6.8	7.4	8.0	8.6	9.3	
8			8.9	9.7	10.5	11.3	12.1	12.9
9				12.2	13.3	14.3	15.3	16.3
10					16.4	17.6	18.9	20.2

[1]Block indicates extent of observed data.

Green Weights

Green weights of the merchantable stem, total stem, and total tree were calculated for each sample tree. Total tree weights refer to all woody portions above stump height. Stumps were approximately 4 inches high. Linear regression procedures were used to develop the equation for the merchantable stem. Constrained regressions were used to obtain prediction equations for green weights of the total stem and total tree.

Green weights of the merchantable stem
(3-inch top outside bark) = $-32.35109 + 0.15544(D^2H)$ (6)

Green weight of the total stem = $0.15397(D^2H)$ (7)

Green weight of the total tree = $0.17231(D^2H)$ (8)

Variation explained by equations (7) and (8) were computed from formula (5). In each case, the equations explained at least 99 percent of the variation in observed green weight. Predicted green weights for merchantable stem, total stem, and total tree are given in tables 3, 4, and 5.

Dry Weights

Dry weights of the merchantable stem, total stem, and total tree were determined from the ovendry weights of the sample disks. Samples from stem bolts, tops, and branches were ovendried to a constant weight

Table 3.--Green weight (including bark) to a 3-inch top diameter (outside bark)[1]

D.b.h. (inches)	Total height (feet)							
	45	50	55	60	65	70	75	80
	Pounds							
4	80	92	104	117	129			
5	143	162	181	201	220	239		
6		247	275	303	331	359	387	
7			387	425	463	501	539	
8			515	565	614	664	714	764
9				723	786	849	912	975
10					978	1,056	1,133	1,211

[1]Block indicates extent of observed data.

Table 4.--Green weight (including bark) of total stem[1]

D.b.h. (inches)	Total height (feet)							
	45	50	55	60	65	70	75	80
	Pounds							
4	111	123	135	148	160			
5	173	192	212	231	250	269		
6		277	305	333	360	388	416	
7			415	453	490	528	566	
8			542	591	641	690	739	788
9				748	811	873	935	998
10					1,001	1,078	1,155	1,232

[1]Block indicates extent of observed data.

Table 5.--Green weight (including bark) of total tree[1]

D.b.h. (inches)	Total height (feet)							
	45	50	55	60	65	70	75	80
	Pounds							
4	124	138	152	165	179			
5	194	215	237	258	280	302		
6		310	341	372	403	434	465	
7			464	507	549	591	633	
8			607	662	717	772	827	882
9				836	907	977	1,047	1,117
10					1,120	1,206	1,292	1,378

[1]Block indicates extent of observed data. Weights do not include leaves.

at 105° C.[2] Percentage of dry matter for each sample was calculated from the formula

$$\frac{\text{Ovendry weight of wood disks}}{\text{Green weight of wood disks}} \qquad (9)$$

The average percentage of dry matter of each merchantable stem was determined by weighting the percentage of dry matter of each bolt by bolt volume. Disk values for the branches were not weighted. Linear regression was used to determine prediction equations for the dry weight of merchantable stems. Constrained regressions were used to derive the equations for dry weights of total stems and total trees.

$$\text{Dry weight of the merchantable stem (3-inch top outside bark)} = -17.67910 + 0.06684(D^2H) \qquad (10)$$

$$\text{Dry weight of the total stem} = 0.06521(D^2H) \qquad (11)$$

$$\text{Dry weight of the total tree} = 0.07431(D^2H) \qquad (12)$$

Equations (10), (11), and (12) accounted for at least 99 percent of the variation in observed dry weights. Predicted dry weights for the merchantable stem, total stem, and total tree are given in tables 6, 7, and 8.

Although the data were collected from a single plantation, they represent the only information available on per-tree volume and weight for sycamore at this time. One should consider the limited data source, however, when using the equations or tables to evaluate or predict early growth and yield of sycamore plantations.

[2]Brown, H. P., Panshin, A. J., and Forsaith, C. C. Textbook of wood technology. 652 pp. New York: McGraw-Hill Book Co., Inc. 1949.

Table 6.--Dry weight (including bark) to a 3-inch top diameter (outside bark)[1]

D.b.h. (inches)	Total height (feet)							
	45	50	55	60	65	70	75	80
	Pounds							
4	30	36	41	46	52			
5	58	66	74	83	91	99		
6		103	115	127	139	151	163	
7			162	179	195	212	228	
8			218	239	260	282	303	325
9				307	334	361	388	415
10					417	450	484	517

[1]Block indicates extent of observed data.

Table 7.--Dry weight (including bark) of total stem[1]

D.b.h. (inches)	Total height (feet)							
	45	50	55	60	65	70	75	80
	Pounds							
4	47	52	57	63	68			
5	73	82	90	98	106	114		
6		117	129	141	153	164	176	
7			176	192	208	224	240	
8			230	250	271	292	313	334
9				317	343	370	396	423
10					424	456	489	522

[1]Block indicates extent of observed data.

Table 8.--Dry weight (including bark) of total tree[1]

D.b.h. (inches)	Total height (feet)							
	45	50	55	60	65	70	75	80
	Pounds							
4	54	59	65	71	77			
5	84	93	102	111	121	130		
6		134	147	161	174	187	201	
7			200	218	237	255	273	
8			262	285	309	333	357	380
9				361	391	421	451	482
10					483	520	557	594

[1]Block indicates extent of observed data. Weights do not include leaves.

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Belanger, Roger P.
1973. Volume and weight tables for plantation-grown sycamore. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-107, 8 pp.

Cubic-foot volumes, green weights, and dry weights per tree are tabulated for plantation-grown sycamore. The regression equations used to predict these parameters are also given.

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USDA Forest Service Research Paper SE-108 June 1973

Site Index: Accuracy of Prediction

by

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Site Index: Accuracy of Prediction

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With the current forecasts of increasing demands for forest products from a decreasing land base, many foresters are preoccupied with ways to increase productivity. Therefore, it is appropriate that foresters take a look at just how well they are evaluating productivity, or site quality, at the present time. Evaluation of site quality has always been an important part of forest management. As management has intensified, accurate estimates have become increasingly important.

For this discussion, we have restricted ourselves to one measure of site quality. That measure is site index, which is defined as the height reached by a forest stand at a selected index age. It can be debated whether or not site index is the best possible measure of site quality. However, over the years it has proved to be a useful indicator. It is widely used for direct estimates, as well as being used as a base for developing and testing alternative methods. Thus, we will confine ourselves to a discussion of how accurately site index can be estimated at the present time and how the accuracy of these estimates might be improved.

In using site index, many foresters are inclined to talk about increments of one unit or possibly even fractions of a unit, which would imply that they are working with a very precise measurement indeed. However, to our knowledge, no set of site index curves or equations comes packaged with a statement of precision or the accuracy one might expect in application. In fact, one usually has no idea of the size of the error involved in any given estimate of site index. Anything that can affect height growth--and there are many factors--can affect one's estimates of site index. Thus, it is extremely difficult to predict the amount of error in such estimates.

Concern with error in estimates of site index is not new. The possible weaknesses in the site index approach were recognized and discussed at the time of its introduction into this country and have been reviewed periodically since then (3, 5, 6, 7). As long-term records have been accumulated, one finds that there are indeed some major sources of error and, thus, avenues for improvement in estimates of site index.

On the basis of recent work, we think that, if conventional site index curves or equations are being used, the estimates of site index are probably biased--quite possibly, seriously biased. By conventional curves, we mean those developed by constructing a single curve of height over age from temporary plot data and then drawing a series of curves for higher and lower sites, harmonized to have the same shape as the guide curve. The majority of the site index curves in use today were constructed by this method. Two major faults of this method prompt us to say that resulting estimates may be biased: disregard of a possible age-site bias in sampling and the assumption of a constant curve shape. An additional and often-overlooked factor which may contribute substantially to errors in estimating site is the improper use of site curves.

SOURCES OF ERROR

Sampling Bias

First, because of patterns of land abandonment and timber harvest, the mean or guide curve of height over age is often distorted. A sample drawn from either natural or planted stands is unlikely to have a uniform distribution of site quality for all ages. For example, a pattern that has occurred in samples for a number of species is that the young age classes contain a preponderance of good sites and the older age classes have a preponderance of poor sites. A sample such as this could result from a cutting pattern: trees reach harvestable size earliest on the best sites; consequently, stands on the highest quality sites may not be available for sampling. Site index curves derived from this sample would tend to underestimate site index at young ages and overestimate site index in older stands. Figure 1 illustrates a distortion associated with a disproportional sample of site and age.

What size error can occur? From stem analysis in 42 stands of eastern white pine (Pinus strobus L.) in the Southern Appalachians, the senior author found that the conventional site curves in use badly underestimated site index in young stands (1). The use of height at age 20 as an input into the existing site curves resulted in underestimates ranging from 8 to 32 feet at index age 50. The average underestimate was 19 feet or nearly two 10-foot site classes. Similarly, in working with loblolly pine (Pinus taeda L.), the junior author found that one set of curves commonly used in the Coastal Plain underestimated site index for a sample of 19 stands by an average of nearly 10 feet when height at age 20 was used (8). In younger stands, the errors were greater.

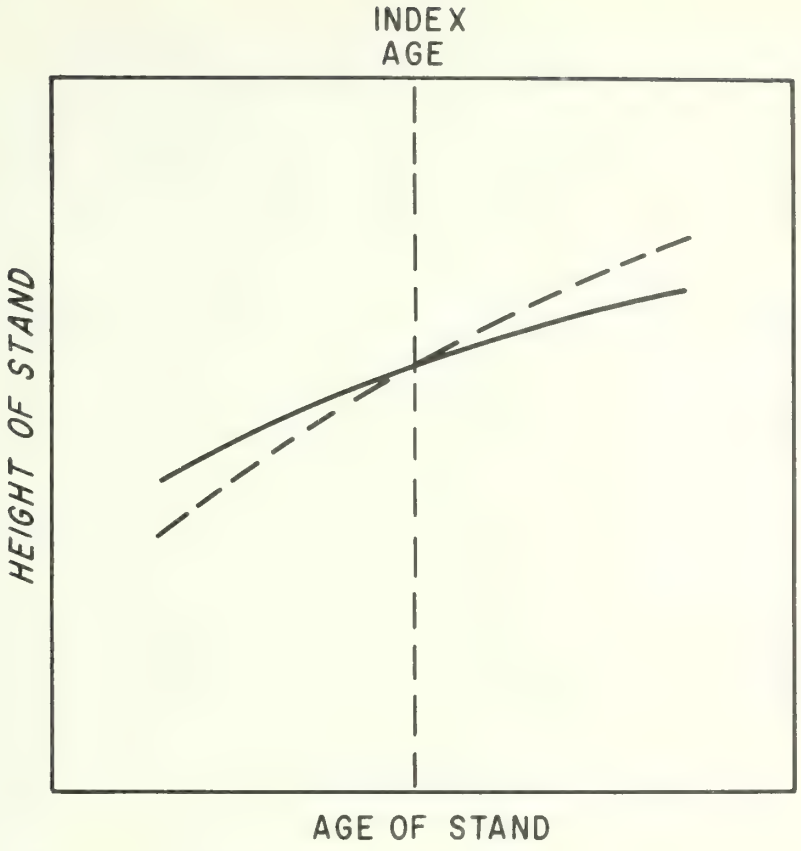

Figure 1.--Disproportional sample of site and age (too many high-quality sites at young age and vice versa) tilts the biased curve (solid line) in comparison with the unbiased curve (dashed line).

Polymorphic Curves

The second major fault of most existing site curves is their inherent assumption that the shape of the height growth curve is the same for all sites. Bull (2) demonstrated in the early thirties that this assumption did not hold in all cases. He showed that the shape of the growth curve varied with site quality in red pine (Pinus resinosa Ait.) plantations, i.e., that it was polymorphic, and, furthermore, that it varied in a definable manner. Similar findings have been increasingly reported for other species in recent years. The degree of diversity in curve shape seems to vary with species and location, but the pattern of growth with changes in site quality is surprisingly similar for many species. Instead of the rates of growth being proportional at all ages for all qualities of sites, as they are usually depicted by conventional curves, the rates of height growth rise rapidly on the best quality sites and then become relatively slow. On the other hand, the growth rates on progressively poorer sites increase more slowly but are maintained for a longer time. In fact, we have found that the rates of height growth for both white and loblolly pines on sites with the poorest site indices are equal to those on sites

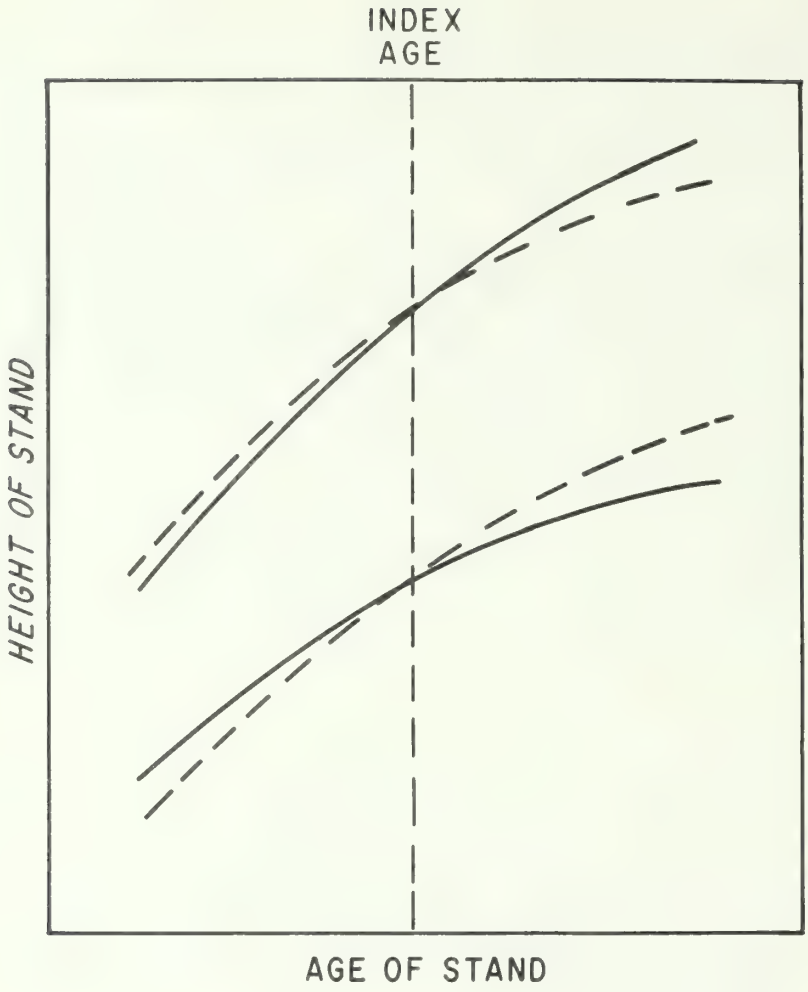

Figure 2.--Curves that assume a proportional relationship (solid lines) are here compared with unbiased, polymorphic curves (dashed lines). As can be seen from the latter, height growth on high-quality sites is rapid at first, but the curves flatten while the stands are still young. In contrast, height growth on low-quality sites is sustained at a slower rate for a longer period.

with the best indices by the time the stands are 50 to 60 years old (fig. 2). Consequently, estimating site index in such stands with site curves that use one similar shape would result in biased estimates.

Given the pattern of growth just described, the size of the bias is likely to be greatest at advanced ages, at 80 to 100 years or older. With present rotations, such bias might be of little but academic interest. However, it can be of some consequence in younger stands. For instance, when height at age 20 was used in the previously mentioned white pine sample, we found that better-than-average sites were overestimated by approximately one site class and below-average sites were underestimated by slightly less than one 10-foot site class if we assumed similar

shape for the index curves. There was a similar but smaller bias with the site curves for loblolly pine. These errors, although not as large as those resulting from sampling bias, are nevertheless serious because of the bias.

Improper Use

One additional, and often overlooked, source of error should be mentioned: the manner of selecting trees on which to base estimates of site index. In most cases, estimates of site index have been based on average height of dominants and codominants. Estimates have also been based on heights of other components, such as dominants only, a fixed number of the largest or tallest trees, and a fixed percentage of the largest or tallest trees. There is really no optimum procedure for all species and all situations. Perhaps the main criterion in choosing trees for such estimates is to apply the curves in a manner consistent with their construction. If a set of site curves was developed on the basis of the 10 tallest trees per acre, then they should be applied on a site to trees selected on the same basis. To do otherwise could negate all the refinements that have gone into the construction of the curves.

IMPROVING ESTIMATES

The first two faults with which most existing site index curves are plagued stem from methodology of construction. These faults can be overcome and the resulting estimates of site index made considerably more accurate by adequate samples that correctly determine curve shape from stem analysis or periodic remeasurements and by analytic methods that recognize differences in curve shape on sites with different qualities. The third fault can be overcome by careful application.

When site curves which eliminated sampling bias and allowed different shapes for different levels of site index were applied to the data on white pine, the senior author found that 70 percent of the estimates in 10-year-old stands could be expected to be within 10 feet of actual site index and 92 percent could be expected to be within 20 feet (1). Of course, the shorter the period to index age, the more precise the estimates. For stands 20 years old, 93 percent of the estimates erred by less than 10 feet. Only an occasional estimate was badly in error. Similar results were found for the loblolly pine stands in the Coastal Plain (8).

But even if site curves are perfectly constructed, diversity in growth patterns caused by different combinations of site factors will lead to a certain amount of error in estimation. Foresters know from experience that stands of exactly the same height at index age may not have grown at exactly the same rate at all ages (fig. 3). Thus, generalized site index curves cannot accurately represent the growth of every individual stand, and errors of estimate are inevitable.

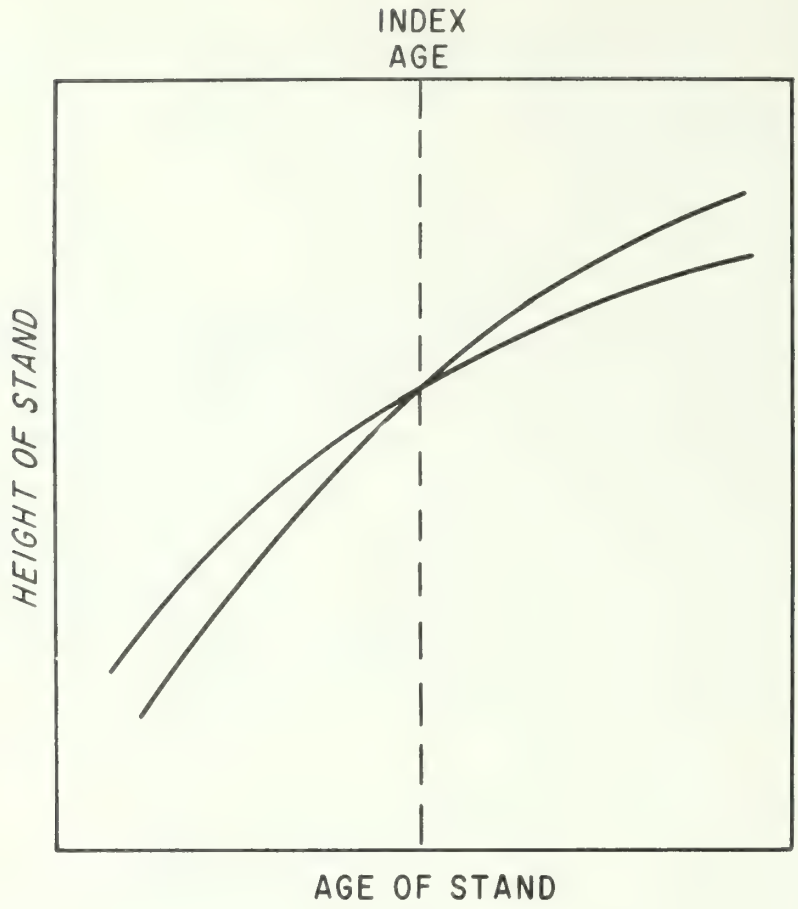

Figure 3.--These two growth curves of identical site index cannot be described without error by a single curve.

The data for white pine in the Appalachian highlands and for loblolly pine in the Coastal Plain represent a wide geographic range, diverse soils, and other environmental factors. Thus, it appears that the improvement that could be obtained in the majority of estimates for these species by recognizing one or a few environmental factors would be relatively small. On the other hand, the literature indicates substantial variation in curve shape (of the type illustrated in figure 3) for some species and for geographical locations (4). Different growth patterns have been associated with specific soil features, vegetative types, and land form categories. For example, Carmean (4) found that height-growth curves for Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) in the Pacific Northwest differed substantially between stands growing on gravels and sands and those growing on soils derived from sandstones and shales. Developing separate sets of site curves for the different soil groups improved estimates of site index.

SUMMARY

It is obvious that site index is not a precise measure of productivity. However, prediction of site index can be improved by using curves that have been developed by stem analysis or other methods that allow detection of true curve form. As a minimum requirement, curves should be used that have been verified by these methods. This one step alone could eliminate a major source of error in many estimates of site index. Additional improvement can be obtained by developing polymorphic site curves that allow the shape of the curve to vary with the quality of the site. For many species, site curves with only this degree of refinement will probably be adequate for most management purposes. In situations where a species grows on two distinctly different sets of soils, it may be profitable to impose a soil classification on the site index system by developing separate sets of curves. Finally, all curves, no matter what their degree of refinement, should be applied in accordance with their construction. Only in this way can maximum accuracy be achieved.

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Site Treatment and Planting Method Alter Root Development of Slash Pine

by
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Site Treatment and Planting Method Alter Root Development of Slash Pine

by

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Forest management in the flatwoods of Florida and south Georgia includes intensive site preparation (e.g., chopping, disking, bedding) and planting for successful establishment and rapid growth of pines (Worst 1964; Wilhite and Harrington 1965; McMinn 1969). In addition to changing the microtopography and drainage patterns, intensive site treatments greatly influence the form and development of root systems (Yeatman 1955; Armson 1958; Haines and Pritchett 1964). Slit planting also deforms the root systems of pine transplants and may ultimately affect their growth and wind firmness (Rudolph 1950; Gruschow 1959; Little and Somes 1964; Klawitter 1969).

This study estimates root biomass and describes root growth patterns of slash pine (Pinus elliottii Engelm.) trees hand- or machine-planted on areas subjected to varying intensities of site preparation.

METHODS

The study included 5 areas in Baker and Union Counties, Florida, and was confined to Leon fine sandy soils (Aeric Haplaquod). These soils are characterized by a spodic horizon beginning at 30 to 50 cm. below the ground surface. The spodic horizon on each study plot varied from a narrow stain layer which did not inhibit development of tree roots to a firm, compacted layer 5 to 15 cm. thick which permitted little root penetration.

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The author wishes to thank Owens-Illinois Inc. for permitting the excavation of all machine-planted trees used in this study.

Table 1.--Effects of site preparation on the development of root systems of slash pine

Site treatment[1]	Spacing	Trees excavated	Time since planting	Avg. tree d.b.h.[2]	Avg. tree height[2]	Primary lateral roots[3]				Taproot	
						Per tree[3]	Avg. length[2]	Deformed	Along planting slit	Avg. length[5]	Deformed
	M.	No.	Yr.	Cm.	Cm.	No.	Cm.	- Percent -		Cm.	Percent
HAND-PLANTED											
Harrow + med. bed	2.4 by 1	23	1	--	35a	4a	61b	--	64	26b	22
Furrow	2.4 by 1	57	1	--	35a	3a	28a	--	63	20a	32
Weighted average				--	35	3	40	--	63	21	29
Harrow	3.7 by 3	5	5	3.3b	250b	14a	289a	61	51	78ab	100
Harrow + low bed	3.7 by 3	5	5	4.8c	280bc	16ab	298a	57	62	95b	60
Harrow + med. bed	2.4 by 1	22	5	3.7b	290bc	29c	251a	43	60	64a	27
Harrow + high bed	3.7 by 3	5	5	5.3c	331cd	22bc	227a	54	59	86b	60
Weighted average				4.0	289	24	260	50	59	73	46
Furrow	2.4 by 2.4	8	12	10.7a	776a	15a	--	--	(4)	129a	(5)
Harrow	2.4 by 2.4	8	12	10.0a	768a	18a	--	--	(4)	90a	(5)
Weighted average				10.4	772	16	--	--	--	109	--
MACHINE-PLANTED											
None	3.7 by 1.8	10	5	2.1a	194a	14a	--	61	69	73ab	50
Harrow + low bed	3.7 by 1.8	20	5	5.5c	359d	20b	--	55	61	92b	30
Weighted average				4.4	304	18	--	57	63	85	37

[1]All treatments were preceded by burning; low beds were 15 cm. above normal ground line; medium beds were 30 cm. above furrow bottoms between beds; high beds were 45 cm. above furrow bottoms between beds; furrows were 7 to 12 cm. below normal ground line.

[2]Numbers followed by the same letter are not significantly different (0.05 level of probability) for trees of the same age.

[3]Roots developing from the taproot which are longer than 0.2 m.

[4]Four trees planted in furrows and six planted in harrowed plots had no lateral roots around one-fourth to one-half of the taproot--probably because of planting in a slit.

[5]Taproots were too large to determine the form at planting.

The root systems of 163 trees were excavated 1, 5, or 12 years after field planting (table 1). Trees were either machine- or hand-planted as 1-0 nursery stock on flatwoods soils which had been prepared by burning followed by (1) no treatment, (2) furrowing, (3) double disk-harrowing, (4) double disk-harrowing plus low bedding, (5) double disk-harrowing plus medium bedding, or (6) double disk-harrowing plus high bedding. Furrows were 1.0 m. wide and 7 to 12 cm. below the normal ground line; low beds were 1.3 m. wide at the base and 15 cm. above normal ground line at their highest points; medium beds were 1.1 m. wide at the base and 30 cm. above furrow bottoms between beds; high beds were 2.5 m. wide at the base and 45 cm. above furrow bottoms between beds. Disking was done with a heavy-duty offset harrow; furrows and medium beds were made with a fireline plow; low beds were made with an 8-foot bedder packer; high beds were made with a fireline plow followed by a bedder packer. All implements were pulled with a crawler tractor. A drag-type planter pulled by a crawler tractor was used for machine planting, and a dibble was used for hand planting.

Among the hand-planted trees, complete root excavation was made for eighty 1-year-old trees and for fifteen 5-year-old trees (table 1). Taproots and superficial lateral roots, to a depth of 15 cm., were completely excavated for the remaining twenty-two 5-year-old trees. Taproots and laterals out to 30 cm. from the bole were excavated for the sixteen 12-year-old trees. Among the 30 machine-planted trees, taproots and laterals out to 30 cm. from the bole were excavated when the trees were 5 years old.

Trees to be excavated were randomly selected, either individually or in small groups, from plantings 2 to 30 ha. in size. Root systems were excavated by a combination of digging and hydraulic excavation at a pressure of 5 kg. $cm.^{-2}$. With care, most roots could be followed to the growing or dead tip. Final removal of large taproots was accomplished by winching. Height, d.b.h., and root measurements were taken in the field for each tree excavated. Roots were taken to the laboratory, washed, separated into tap or lateral roots, ovendried at 105° C. to a constant weight, and weighed to estimate biomass.

Tops of selected trees were separated into bole, branches, and needles and then ovendried and weighed to estimate biomass.

Analyses of variance and chi-square tests were used to determine the effects of site preparation on root development, as well as on dry weights of roots and shoots.

RESULTS AND DISCUSSION

One-Year-Old Trees

Lateral roots.--The maximum length of lateral roots was 79 cm. for trees planted in furrows and 140 cm. for those growing on medium beds; average root lengths were 28 cm. for the former and 61 cm. for

the latter (table 1). These significant differences (0.05 level of probability) show the value of bedding in water regulation and early root growth and indicate that, even though height growth is slow during the first year after planting, lateral root growth can be rapid. Kaufman (1965) found roots of irrigated and cultivated slash pine up to 9.5 m. long at age 3.

Taproots. --Average length of taproots was significantly greater for trees on beds than for those in furrows, probably because bedded trees were farther from the water table (table 1). Many trees planted in furrows had dead taproots at the water table. The percentage of deformed taproots was also 10 percent higher in furrows than on beds. This difference was not statistically significant but may have been due to a high water table at the time of planting.

Biomass. --One-year-old trees on beds were no taller than those in furrows, but their total dry weight was 2.3 times greater (18.3 vs. 7.8 g.). This difference in early biomass may be an important reason why trees growing on beds ultimately show more rapid height growth than trees growing on flat-harrowed areas during the first few years after planting (Langdon 1962; Haines and Pritchett 1964; McMinn 1969).

Taproot form did not significantly affect total dry weight or tree height.

Five-Year-Old Trees

Lateral roots. --Primary laterals averaged 260 cm. long (table 1). Most laterals were initiated within 20 cm. of the soil surface (table 2). Most long roots grew within 10 cm. of the soil surface and were often less than 1 cm. below the surface. Primary laterals which were bent down at planting or were planted deep in the soil soon turned up and grew near the surface. Roots which were initiated 30 to 40 cm. below the surface were much shorter than surface laterals and proliferated in or near the spodic horizon. Many laterals had dead tips, but it is not unusual for roots to die back, form new tips, and elongate again (Kaufman 1965).

Fifty-four percent of all lateral roots were deformed--an average of 11 deformed lateral roots per tree. Although 50 percent of the laterals of hand-planted trees and 57 percent of those of machine-planted trees were deformed (significantly different at the 0.05 level of probability), root deformation of only one hand-planted stand was outside the range of 54 to 61 percent. Nearly all laterals of some trees were severely bent or twisted around the taproot (fig. 1). Bent lateral roots were probably caused by slit planting, but twisted laterals were caused by planters who rolled the lateral roots around the taproot for ease of planting. Many of these twisted lateral roots were killed by roots which grew around them. As with previous studies (Rudolph 1950; Gruschow 1959; Hay and Woods 1968; Sutton 1969), results of the present study give no clear indication that early growth is inhibited by poor planting.

Table 2.--Effects of site preparation on the development of 5-year-old hand-planted slash pine[1]

Characteristic (average per tree)	Site preparation			
	Disk-harrow + high bed	Disk-harrow + low bed	Disk-harrow	Significant difference[2]
Trees excavated (No.)	5.0	5.0	5.0	
Tree d.b.h. (cm.)	5.3	4.8	3.3	**
Tree height (m.)	3.3	2.8	2.5	**
Lateral roots (No.)[3]	22.2	16.0	13.8	ns
Along planting slit (No.)[4]	13.2	10.0	7.0	*
Other orientation (No.)[4]	9.0	6.0	6.8	ns
Deformed lateral roots (No.)	12.0	9.2	8.4	ns
Average length of lateral roots (m.)	2.3	3.0	2.9	ns
Longest root (m.)	4.5	5.7	5.9	ns
Roots longer than bole (No.)	3.6	8.8	7.4	**
Lateral root diameter (cm.)	0.8	0.8	0.7	ns
Depth of origin of lateral roots				
0 to 10 cm. (No.)	4.6	1.0	3.8	ns
11 to 20 cm. (No.)	12.4	10.0	6.6	ns
21 to 30 cm. (No.)	3.8	2.6	2.0	ns
31+ cm. (No.)	1.4	2.4	1.4	ns
Sinker roots from laterals (No.)	14.0	17.2	7.2	ns
Sinker roots on beds (No.)	11.5	6.2	--	ns
Maximum depth of sinkers (cm.)	91.0	85.0	76.0	ns
Maximum depth of rooting (cm.)	110.0	98.0	83.2	ns
Taproot depth (cm.)	86.0	95.0	77.8	ns
Deformed taproots (No.)	3.0	3.0	5.0	ns
Root dry weight (g.)	1,164	836	566	*
Taproot (g.)	558	450	313	*
Lateral roots (g.)	606	386	253	ns
Top dry weight (g.)	4,232	3,413	2,201	**
Bole (g.)	2,363	1,769	1,197	**
Branches (g.)	498	448	215	**
Needles (g.)	1,371	1,196	789	*
Total dry weight (g.)	5,396	4,249	2,767	*
Root/shoot ratio	.28	.24	.26	

[1]Excavated trees were randomly selected from among trees of average height and diameter for each treatment.

[2]* = significant at the 0.05 level; ** = significant at the 0.01 level; ns = nonsignificant.

[3]Lateral roots are first-order roots originating from the taproot.

[4]The area around each tree was divided into four quadrats. Two of the quadrats were bisected by the planting slit; the other two were at right angles to the planting slit.

The trees had relatively few roots at right angles to the planting slit (fig. 2). Sixty-one percent of all lateral roots grew in the direction of the planting slit (table 1). Forty percent of all hand-planted and 47 percent of all machine-planted trees excavated had fewer than two roots in one or both quadrants at right angles to the planting slit. This difference was not statistically significant. Trees developing in place from seed have laterals which grow away from the taproot in all directions (Little and Somes 1964).

Figure 1. --Lateral roots of this dibble-planted 5-year-old tree are twisted and concentrated in a single plane.

Excavations were made of five additional hand-planted trees blown over by a high wind. In each case, there was one or no lateral root growing to the windward side of the tree. All had deformed taproots, but the primary reason for blowdown was compression of the lateral root system as a result of slit planting.

Bedding changed the soil surface from flat to undulating (fig. 2) and altered root development (tables 1 and 2). The average number of primary laterals per tree ranged from 29 on medium beds to 14 on unprepared or harrowed areas. This difference was significant at the 0.05 level of probability. The average length of lateral roots was not affected by site treatment, but trees planted on high beds had significantly fewer laterals longer than the bole (4) than did trees on low beds (9) or those on areas that were harrowed only (7). The maximum length of lateral roots was 6.5 m. for trees on high beds, 6.1 for those on medium beds, 6.8 m. for those on low beds, and 7.5 m. for those on harrowed plots. These same trees were 3.8, 2.9, 2.8, and 2.7 m. in height, indicating that the extension of lateral roots on young trees is greater than tree height.

Most lateral roots of trees planted on high beds proliferated in the furrow bottoms or along the sides of the beds. Laterals from low beds usually grew under the small furrows and into the flat or even into the

Figure 2.--Superficial lateral roots of 5-year-old trees dibble-planted on medium beds. Roots were compressed into a slit at right angles to the direction of the beds. Few roots grew along the beds. The roots are sprayed with white paint for better visibility.

next bed. Primary laterals of trees planted on flat-harrowed areas had the least proliferation. Although trees growing on beds formed an average of twice as many sinker roots as those on flat-harrowed areas, the variation among trees was so great that differences were nonsignificant.

Taproots.--Many trees had deformed taproots as a result of planting. Deformed taproots were found on 46 percent of the hand-planted trees and on 37 percent of the machine-planted trees. This difference was not statistically significant. Only medium bedding significantly altered taproot length (table 1), probably because the site with medium bedding was somewhat wetter than the others. Because the spodic varied in density and thickness, the taproots of some trees were restricted (fig. 3) while those of their neighbors were relatively unaffected.

Biomass.--Site preparation significantly altered the root, top and total dry weights (table 2). Top weight of trees on high beds was 24 percent greater than that of trees on low beds and 92 percent greater than that of trees on flat-harrowed plots. Root weight of trees on high beds was 39 percent greater than that of trees on low beds and 106 percent greater than that of trees on flat-harrowed areas. On all sites, belowground biomass ranged from 20 to 22 percent of the total dry weight, indicating that the root/shoot ratio was not altered by treatment.

Figure 3.--A dense spodic horizon 60 cm. below the soil surface restricted the rooting of a 5-year-old tree. Lines on backdrop are at 0.3-m. intervals.

Trees growing on high-bedded plots were 32 percent taller and 60 percent larger in diameter than were trees growing on disk-harrowed plots. Low bedding was intermediate for both measurements (table 2).

The biomass of trees with deformed taproots was not significantly different from that of trees with straight taproots.

Twelve-Year-Old Trees

Lateral roots.--The effects of root deformation at planting were greatly masked by age 12. Lateral roots were overgrown as the taproot diameter increased, and few deformed roots remained visible (fig. 4).

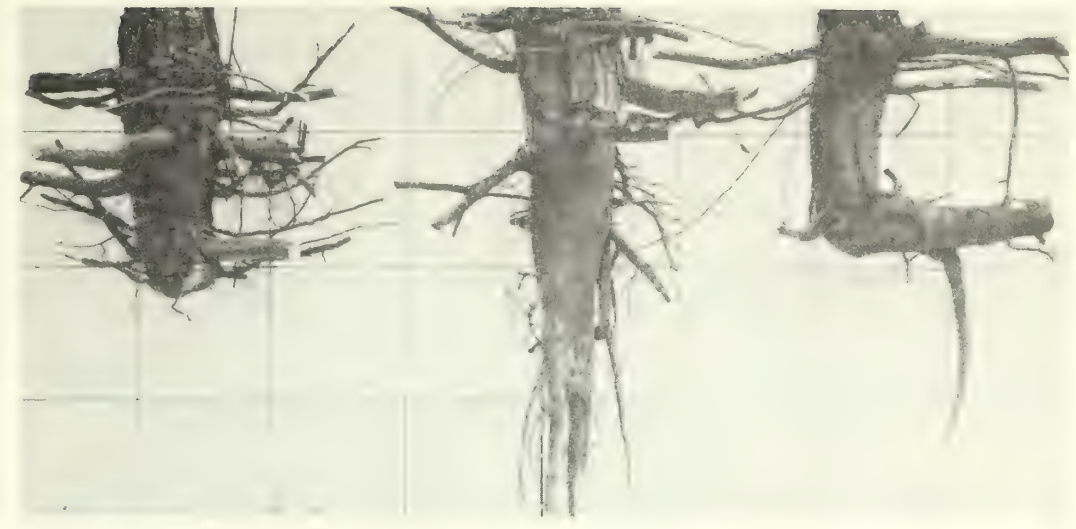

Figure 4.--Twelve-year-old trees with unrestricted development of a taproot through a soft spodic (center) and restricted rooting caused by a dense spodic horizon (left, right). The center and right-hand trees were growing 2 m. apart. Lines on backdrop are at 0.3-m. intervals.

The effects of slit planting were still visible, however, because 10 of 16 root systems excavated had no roots around one-fourth to one-half of the total taproot circumference.

Twelve-year-old trees had significantly fewer lateral roots (0.05 level of probability) than did 5-year-old trees. This difference was probably due to the intensity of treatments: there was no significant difference in number of lateral roots on 5- and 12-year-old trees on plots with the same site treatment (harrowing). These results indicate that most primary lateral roots are formed by age 5 in this species.

Taproots.--The spodic horizon greatly altered root systems (fig. 4). Taproots of 6 trees (37 percent) were completely blunted or bent by a firm spodic horizon. Other trees, growing as close as 2 m. to those with deformed taproots, had straight taproots which grew through the spodic horizon. Firmness of the spodic horizon is probably the main factor limiting taproot development. Although level of the water table undoubtedly affects root development, tree roots can grow and function well below the water table (Schultz 1972).

Taproot form did not significantly alter aboveground growth.

CONCLUSIONS

Slit planting greatly deformed the root systems of slash pine and was the cause of some blowdown in young plantations. There was little difference between machine and hand planting in the number of deformed

taproots and lateral roots; however, the deformities of hand-planted trees (balled or J-rooting) are more serious than the L-rooting which was common for machine planting. Whether the trees were hand- or machine-planted, the majority of their roots grew in the direction of the slits, subjecting the trees to windthrow at right angles to the planting slits.

Root deformation at planting did not appear detrimental to tree growth. By the time the trees reached 12 years of age, diameter growth of the taproot had masked most root deformation. Although bent roots are inherent in the technique of slit planting, the practice of twisting lateral roots around the taproot prior to planting should be eliminated because some of these roots ultimately die. Proper root pruning when lifting or grading seedlings should keep this problem to a minimum.

When compared with flat-harrowing, bedding significantly increased both the root and shoot biomass of 5-year-old trees. Although bedding did not increase height growth over flat-harrowing the first year, increased root elongation and total biomass resulted in significant growth differences through age 5. The trees growing on high beds had the most rapid rate of early growth.

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Excavation of slash pines 1, 5, and 12 years after intensive site preparation and machine or hand planting on a Spodosol in the northeastern Florida flatwoods revealed that 35 percent of the taproots and 54 percent of the lateral roots were deformed by slit planting, which resulted in roots extending at right angles to the slit so that the trees were susceptible to windthrow. Balled and J-shaped taproots were common among hand-planted trees, and L-rooting prevailed among machine-planted trees. Root deformation at planting could not be correlated with tree growth. On 5-year-old trees, high bedding resulted in significantly fewer long lateral roots (4) than did disk harrowing (7) or low bedding (9). Dry weight of roots averaged 1,164 g. for trees on high beds, 836 g. for trees on low beds, and 566 g. for trees on disk-harrowed plots. Top weights showed similar significant differences.

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Soil and Foliar Guidelines for Phosphorus Fertilization of Loblolly Pine

by

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INTRODUCTION

There are extensive areas of soils deficient in phosphorus (P) in the southeastern Coastal Plain. Previous studies have shown that the growth rate of southern pine on some sites has been increased by P fertilization. In one case, under conditions of low soil and needle P, loblolly pines (Pinus taeda L.) at age 3 were 6.8 feet tall on plots fertilized with 25 or 50 pounds of P per acre and only 3.7 feet tall on nonfertilized plots (Wells and Crutchfield 1969). Average tree height at age 5 was 14.8 feet on the same P-fertilized plots and only 8.0 feet on the nonfertilized plots. Results of this type demonstrate the practical aspect of P fertilization where needed.

Soil tests and foliar analysis are means to detect soils which need P fertilization. Foliar analysis has been more reliable than soil tests for prediction of increased growth of southern pines from P fertilization (Pritchett 1968; Wells and Crutchfield 1969). A reliable soil test would have more utility than needle analysis because soils could be tested and fertilizers applied before or soon after planting. The use of needle analysis is not possible on some sites because loblolly pine trees are not available before regeneration or they are suppressed to such an extent that needle content would not be indicative of soil fertility. Soil samples are also easier to collect than needles, especially from large trees. In assessing fertility, information on more than one element is desirable,

and such information can be derived from soil tests. One deficient element may cause foliage to be high in other elements which will not be in adequate supply when deficiency of the first element is corrected. A high level of needle N (nitrogen) has been observed when P is deficient, because tree growth is not sufficient for the available N to be utilized. This imbalance in nutrients is the basis of the N/P ratio as a guide to P fertilization (Raupach 1967).

Generally, soils in the Southeast are acid, and P is found in combinations with Fe, Al, Ca, and organic matter. Various chemical forms of P are adsorbed on soil particles, and these forms are believed to be important sources of P for plants. A soil test should extract a quantity of P correlated with the amount plants can obtain from the soil. In turn, the results of soil tests, when properly interpreted, would indicate the need for fertilization. Soil P tests have been developed with different chemical extractants in order to measure the so-called "available P" to plants. In certain instances, good correlations have been found between the amount of available P extracted and the response of crops to P fertilization.

Two widely used P extractants, the Bray No. 2 (0.1$\underline{N}$ HCl + 0.03$\underline{N}$ NH_4F) (Bray and Kurtz 1945) and the one adapted by the North Carolina Soil Testing Laboratories[1] (0.05$\underline{N}$ HCl + 0.025$\underline{N}$ H_2SO_4), are considered effective for extraction of available P. Loblolly pine obtains adequate P on soils low in fertility by standards used for agronomic crops. Therefore, it is often suggested that ectomycorrhizae or certain root characteristics enable this pine to obtain P from relatively insoluble forms. Total P has been used as a guide for P fertilization of pine in Australia (Baur 1959). In trials with different extractants, P extracted by 1.0$\underline{N}$ NH_4OAc (pH 4.8) was more highly correlated with response to P fertilization of slash pine in Florida than was total P or P extracted by several other solutions (Pritchett and Llewellyn 1966). In the South Carolina Piedmont, P extracted by 0.002$\underline{N}$ H_2SO_4 (pH 3.0) and 0.1$\underline{N}$ HCl + 0.03$\underline{N}$ NH_4F was more closely related to P in loblolly pine needles than was total P (Wells 1965). Loblolly pine on Tatum silt loam in the Virginia Piedmont did not respond to P fertilization in 10 years after fertilization even though soil P was only 4.5 kg./ha. by 0.05$\underline{N}$ HCl + 0.025$\underline{N}$ H_2SO_4 extraction (Moschler, Jones, and Adams 1970). These results indicate that a P extractant stronger than the 0.1$\underline{N}$ HCl + 0.03$\underline{N}$ NH_4F solution might have merit.

Before a soil test can be used for recommendation of fertilization, field studies must show that the test will be useful for the differentiation of soils into groups in which pine will and will not respond to fertilization. For both foliar analysis and soil tests, knowledge of the physiology of the plant and of the physical and chemical nature of the soils, along with a good understanding of the ecology of each site, are necessary in order to relate the laboratory analysis to tree growth. The response from correction of a specific nutrient deficiency is often limited by factors about

[1] Soil Testing Division of the North Carolina Department of Agriculture, Raleigh, N.C

which less information is available, such as excessive water in the Coastal Plain or lack of water in the Piedmont, competition from weeds, and deficiencies of other elements. For these reasons, results of field research are variable and more information is desirable if fertility and management practices are to be continually improved.

The purpose of the present investigation was to evaluate and calibrate soil tests and foliar analysis as methods to predict response to P fertilization. These evaluations were intended to serve as the basis for more dependable recommendations on the use of soil tests and foliar analysis for loblolly pine in the Piedmont and Coastal Plain.

METHODS

Field

Tree height was measured and soil and needle samples were collected from 3-year-old loblolly pine on fertilization plots in the Coastal Plain of South Carolina and the Piedmont of Virginia and South Carolina. A soil sample was collected from each plot by compositing 15 to 20 sampling-tube cores from the 0- to 8-inch depth. A composite needle sample was collected from 10 to 20 trees per plot by taking five fascicles from upper lateral branches of the first flush of the previous spring.

There were 11 studies in the Coastal Plain with applications of 20 to 50 pounds of P per acre; these studies were comprised of 40 paired plots with and without P. In the Piedmont, there were nine studies with P rates of 50 to 200 pounds per acre; these studies were comprised of 52 paired plots. All plots contained at least 20 trees for measurement inside similarly treated border areas. The studies differed in design, consisting of experiments with one to three P rates and from two to five replications but in all cases containing paired plots with and without P. The P fertilizer was usually broadcast on the soil surface at about planting time. In one Piedmont study, fertilizer was placed in the closing holes when the seedlings were hand planted; in one Coastal Plain study, fertilizer was applied in 4-foot-wide bands and the plots were then bedded. Planting was both by hand and machine on beds in the Coastal Plain and on site-prepared land in the Piedmont. The P source was triple superphosphate except for a source comparison with normal superphosphate in one study.

At age 3, a relatively short time in terms of response after P application and planting, no significant differences in response were found for rates, application techniques, or P sources. Because no differences were found, rates, methods, and P sources were used in the same way to test for response to P fertilization.

The Piedmont sites were on upland soils which were moderately well drained to well drained. Studies in the Coastal Plain were all on bedded sites previously prepared as required for a satisfactory bedding operation. These soils ranged from very poorly drained in a Coxville loam to moderately well drained in a Chipley loamy sand.

Laboratory

Soil samples were air-dried and ground to pass a 2-mm. mesh sieve. Extractions for available P and cations were made by shaking 5 ml. (approximately 5 g.) of soil measured in a calibrated scoop and 50 ml. of extracting solution for 5 minutes and then filtering. Available P extractions were made with the North Carolina (N.C.) (0.05N HCl + 0.025N H_2SO_4), Bray No. 2 (0.03N NH_4F + 0.1N HCl), and 5N HCl solutions. Total P was estimated by digesting 2 g. of soil in 6 ml. of a 1:1 mixture of 60-percent $HClO_4$ and 98-percent H_2SO_4 for 2 hours on a semi-micro-Kjeldahl apparatus (Ng 1970). Exchangeable K, Ca, and Mg were extracted with N NH_4OAc at pH 7 and Al by nonbuffered N KCl.

Needle samples of 0.5 g. were ashed in a muffle furnace at 450° C. for 4 to 6 hours. After ashing, 2 ml. of concentrated HCl were added and evaporated without boiling. Just as the samples reached dryness, they were removed from the hotplate and 20 ml. of 0.4N HCl plus 0.2-percent La solution were added. After 4 hours and two intermittent stirrings, the solution was poured into vials and the residue was allowed to settle for at least 16 hours.

Phosphorus was determined in the plants by the colorimetric vanadomolybdate method and in the soil extractants by molybdenum blue. Cations were determined by an atomic absorption spectrophotometer, N was determined by Kjeldahl, and soil C was determined by the Walkley-Black procedure (Jackson 1958).

Statistical

Correlations, regressions, and plotting methods were used to determine the relationships among soil and needle variables and tree height. A response index to P fertilization was calculated by the formula

$$\text{Response index} = \frac{\text{Height of trees on P-fertilized (P+) plots}}{\text{Height of trees on nonfertilized (Po) plots}} \times 100$$

Response index was then related to soil and needle variables.

RESULTS AND DISCUSSION

Application of P fertilizer consistently increased needle P in both the Piedmont and Coastal Plain. Tree height at age 3 was significantly increased by P fertilization on several Coastal Plain sites. A response to P was indicated in certain Piedmont sites, although it was not statistically significant at the 10-percent level. Without application of P (Po plots), soil P (N.C.) and needle P were correlated with height at age 3 in the Coastal Plain. On Po plots, significant correlation coefficients were found between height at age 3 and p.p.m. of soil P by the N.C. extractant ($R^2 = 0.46$) (fig. 1) and between height at age 3 and percentage of P in the needles ($r^2 = 0.31$) (fig. 2). Either of these two methods will predict the expected tree height at age 3. On the basis of these relation-

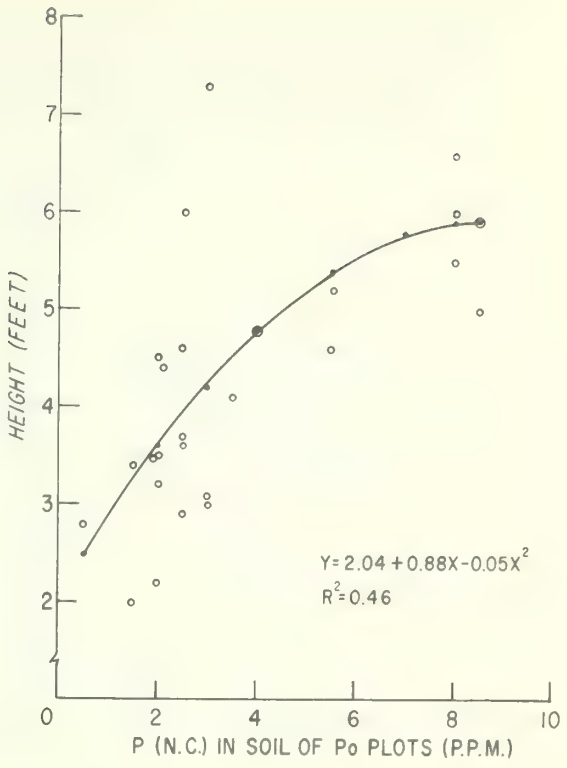

Figure 1.--Relationship between soil P (N.C.) and height of loblolly pine at age 3 on the nonfertilized (Po) plots in the Coastal Plain.

ships between soil or needle P and tree height, the effects of P fertilization can be evaluated to determine the critical level of soil or needle P below which P fertilization will increase growth and above which growth will not be increased by P fertilization.

Piedmont

For the Piedmont studies, correlation coefficients (r) between soil P and tree height at age 3 and between needle P and tree height were less than the 0.37 required for significance at the 5-percent level. The r for relationships between height and phosphorus predictor variables of Po plots in the Piedmont were: needle P, -0.14; soil P (N.C.), -0.34; soil P (Bray No. 2), -0.30; soil P (5N HCl), -0.30; and total soil P, -0.31. The r for relationships between tree height and other variables were: fascicle weight, 0.67; needle N, -0.14; needle K, 0.22; needle Ca, -0.37; needle Mg, -0.64; needle Mn, -0.06; needle Zn, -0.11; needle Cu, -0.61; needle Fe, -0.14; needle Al, 0.26; soil K, -0.25; soil Ca, -0.49; soil Mg, -0.30; soil Al, 0.70; soil N, 0.36; and soil C, 0.65.

Interesting speculations can be developed concerning the negative correlations between height and P and the positive correlations between height and Al. Further research is required to establish cause-and-effect relationships for these data. Without a meaningful relationship between P in the soil or needles and tree height, or a clear growth increase from P fertilization, we are without a basis for prediction of response to P fertilization in the Piedmont. Therefore, most of this report deals with data from the 11 studies in the Coastal Plain.

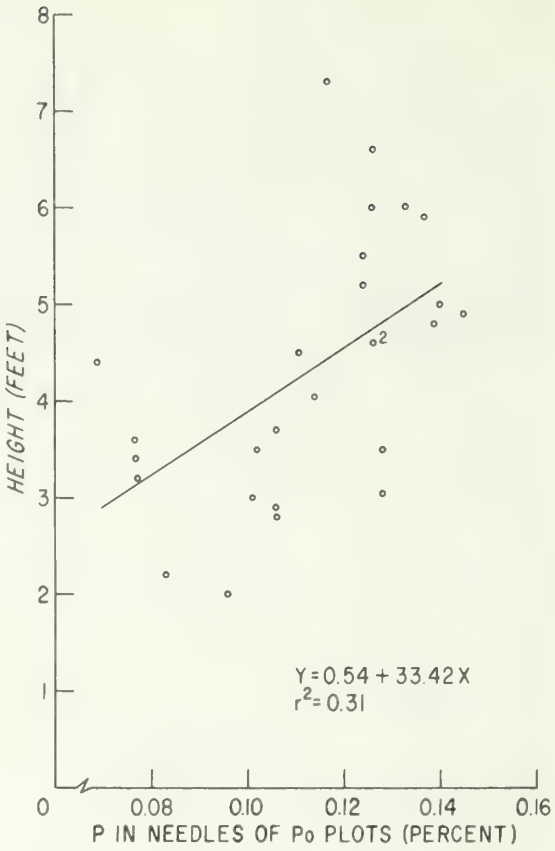

Figure 2.--Relationship between percentage of P in needles and height of loblolly pine at age 3 on the nonfertilized (Po) plots in the Coastal Plain.

Coastal Plain

Tree Height and Soil and Needle Variables

On Coastal Plain sites, a significant correlation was found between tree height and several parameters (table 1). Generally the r was positive for height on Po plots with soil P by N.C. and Bray No. 2 extractants. Needle P and fascicle weight showed strong relationships with height.

On the P+ plots, correlations were negative between height and extractable soil P (both N.C. and Bray No. 2) and needle P; but there were strong positive correlations with total soil P and soil N, K, Al, C, and C/N ratio. Height and C and C/N ratio were probably correlated because C and N are correlated and N was related to height. The shift from positive to a lower negative r between height and extractable soil P (N.C., Bray No. 2, 5N HCl) on the P+ plots suggests that, when P was applied to a P-deficient soil, the P need was satisfied, and one or more other factors became growth limiting. The strong positive r for the relationship between height and soil N indicates that N would be the next most limiting factor. Work reported for slash pine in Florida shows a response of young trees to N (Pritchett and Smith 1972). Soil K, Al, and total P were positively correlated with C and N. These relationships provide an explanation of the positive correlations between these elements and height on P+ plots.

Table 1.--Correlation (r) of soil and needle variables with height and response to P at age 3

Variable	Height on--			Response to P[4]
	Po plots[1]	P+ plots[2]	P+ plots[3]	
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Soil P				
N.C.	0.54*	-0.30	0.10	-0.48*
Bray No. 2	.62*	-.38*	.39*	-.27
5N HCl	.40*	-.30	.47	-.19
Total soil P	.31	.65*	ND	-.16
Needle				
P	.56*	-.19	-.29	-.75*
N	.18	.14	.53*	.12
K	0	-.26	-.30	-.24
Ca	.05	-.51*	-.65*	-.56*
Mg	-.16	-.43*	-.65*	-.39*
Mn	-.11	-.42*	-.54*	-.31*
Al	.20	-.38*	-.38*	-.54*
Cu	.07	-.12	.03	-.03
Zn	-.17	-.32	-.16	-.07
Fe	-.18	-.13	ND	ND
Na	.29	.28	ND	ND
Fascicle weight	.58*	.06	ND	ND
N/P	-.29	.39*	.57*	.64*
Soil				
N	.02	.75*	.75*	.44*
K	0	.54*	.54*	.41
Ca	.38*	.02	.02	-.27
Mg	.20	.23	.23	.05
Al	-.29	.61*	.61*	.58*
pH	.29	-.28	-.29	-.37*
C	.04	.72*	.72*	.40*
C/N	0	.69*	.69*	ND

[1]Height of Po plots correlated with soil and needle variables of the same plots.

[2]Height of P+ plots correlated with soil P and needle variables of P+ plots and soil N, K, Ca, Mg, Al, pH, and C of Po plots of the replicate.

[3]Height of P+ plots correlated with soil and needle variables of paired Po plots.

[4]Response to P fertilization correlated with soil and needle variables of paired Po plots.

*Significant at the 5-percent level or greater. ND = not determined.

Levels of Soil and Needle P

The height of trees on the various Po plots at age 3 ranged from 2 to 7 feet (fig. 1). The range in height for a given P level in the soil or needles is caused by factors other than the P influence on height. Other soil factors which enhance growth are correlated with soil P and jointly contribute to good height growth. When the data for the Po plots are considered, it seems desirable to have a P level of about 7 p.p.m. in the soil (N.C.) and 0.13 percent in the needles (figures 1 and 2). Because many factors affect growth, it would be unsafe to assume that fertilization to increase soil P to 7 p.p.m. or needle P to 0.13 percent would consistently produce trees 6 feet tall at age 3.

Response to fertilization is the real test for fertilizer need under existing soil conditions. Figure 3 shows that a response to P fertilization is likely if needle P is 0.10 percent or less. When needle P was 0.09 percent or less on Po plots, the height was about 80 percent greater on the P+ plots than on the Po plots. The regression for response to P fertilization as a function of needle P is highly significant, with an R^2 (coefficient of determination) of 0.60. These results agree well with the critical foliar level of 0.11 percent previously established for needles of loblolly pine 1 year after planting (Wells and Crutchfield 1969).

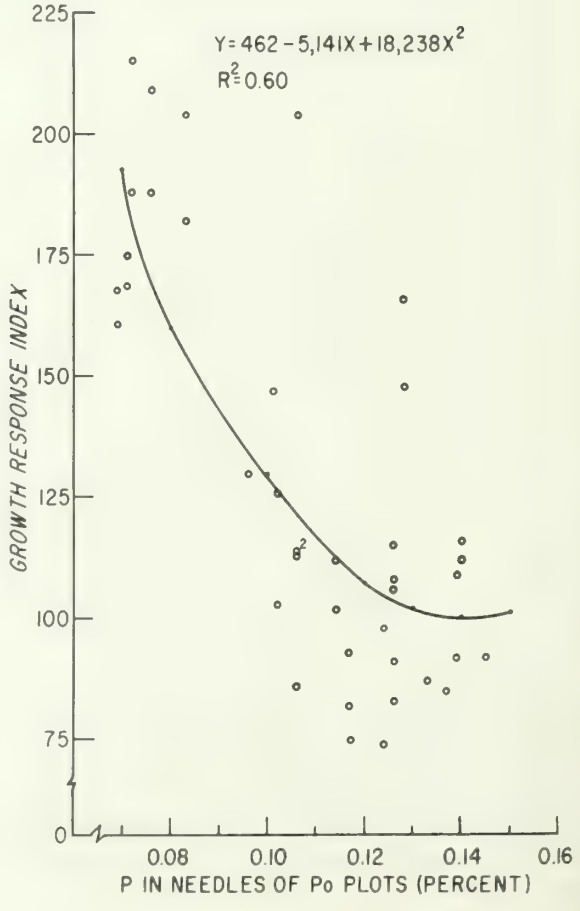

Figure 3.--Growth response index at age 3 after application of 20 to 50 pounds of P per acre in relation to P in needles of Po plots of the same replicate.

The relationship between soil P (N.C.) and response to P fertilization was not linear (fig. 4). Neither did the plotted data fit the second-order regression as used by Pritchett (1968) to predict the response of slash pine to P fertilization. However, figure 4 shows a useful separation of plots on the basis of the N.C. extractant for soil P. The Cate and Nelson (1971) procedure for partitioning data on soil test correlations into two classes was applied to our data to determine the critical level of soil P (N.C.). The procedure is to split the data into two groups by using successive tentative critical levels to ascertain that particular critical level which will maximize overall predictive ability (R^2), with the means of the two groups as the predictor values.

By the Cate and Nelson procedure, the maximum R^2 of 0.38 was obtained when soils with 2.3 p.p.m. or less of P formed a group with a mean response index of 158--or a response of 58 percent. The mean response index was 108 for plots with greater than 2.3 p.p.m. of P in the

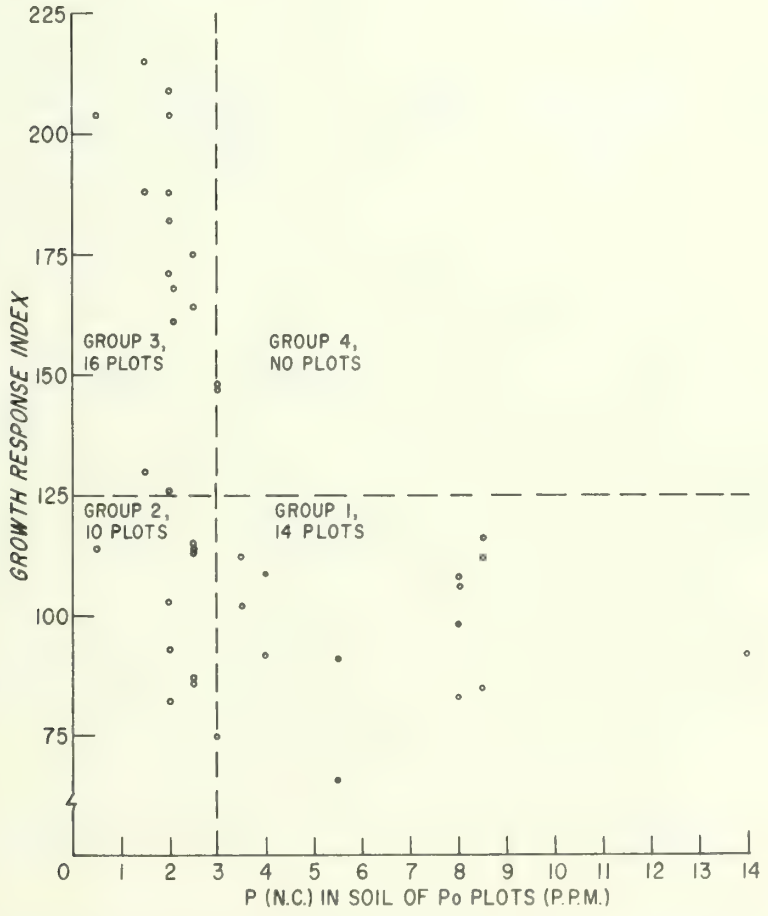

Figure 4.--Growth response index at age 3 after application of 20 to 50 pounds of P per acre in relation to soil P (N.C.) of Po plots of the same replicate. See text for explanation of the control lines and the various groups of plots.

soil. When the two groups were partitioned at 3 p.p.m. of P, the mean response indices were 145 for the soils at 3 p.p.m. or less and 98 for those greater than 3 p.p.m., and the R^2 value was 0.33.

Growth response index was less than 120 on soils with more than 3 p.p.m. of soil P. Drawing in broken control lines in figure 4 at 3 p.p.m. of P and 125 growth response index breaks the data into four groups:

Group 1--soils with over 3 p.p.m. of P and no growth response

Group 2--soils with 3 p.p.m. of P or less and no growth response

Group 3--soils with 3 p.p.m. of P or less and a good growth response

Group 4--soils with over 3 p.p.m. of P and good growth response.

There were no plots in Group 4. On the basis of this classification, 3 p.p.m. of P (N.C.) is the critical level of soil P. The several plots in Group 2 show that, on some soils, trees do not respond to P fertilization even when soil P is very low. However, none of the plots with soil P greater than 3 p.p.m. responded to P fertilization, and this lack of response makes possible the exclusion from fertilization of part of the soils where fertilization will not improve tree growth. Further investigation of reasons for no response to P on some plots in Group 2 is warranted.

Factors Preventing Response on Soils Low in P

There are two possible reasons for the lack of response to P on the plots with 3 p.p.m. or less of P: (1) An adequate supply of P was available to the trees although the soil test was very low, or (2) other factors limited growth and thus prevented the trees from responding to P. There were probably two or three plots that fell in category (1). Most of the plots would be in (2). An analysis of factors limiting response to P was pursued by comparing the soil properties of the plots in each of the three groups in figure 4 (table 2). Notice that when Group 2 (plots low in P but not responding) is compared with Group 3 (plots low in P and responding), needle P is higher on Po and P+ in Group 2. This difference accounts for the somewhat better correlation between needle P and response index than between soil P and response index. Application of P tended to decrease needle N in Group 3 because of improved growth and the dilution process. Needle Mn and Al are greater in Group 2 than in Group 3, but Al is still higher in Group 1 where growth was good. Danielson[3] found that Mn, Fe, and Al accumulated in greater concen-

[3]Danielson, R. M. The effect of soil fumigation on seedling growth, mycorrhizae and the associated microflora of loblolly pine (Pinus taeda L.) roots. 1966. (M.S. Thesis, N.C. State Univ. at Raleigh, Dep. Soil Sci., 148 pp.)

trations in loblolly pine seedlings which grew more rapidly as a result of soil fumigation. Group 2 differs from both Groups 1 and 3 in soil N. This indication that soil N was limiting growth is in agreement with the positive correlation between height and soil N on P+ plots (table 1), as discussed earlier. Total evaluation of data in table 2 indicates that N deficiency and possibly other factors prevent trees in plots of Group 2 from responding to P fertilization.

Table 2.--Characteristics of plots by response group

Variable	Treatment	Group 1[1] Soil P > 3 (N.C.) No response	Group 2[2] Soil P ≤ 3 No response	Group 3[3] Soil P ≤ 3 Good response
Height, ft.	Po	5.2	4.4	3.2
	P+	5.1	4.1	5.6
Soil P (N.C.), p.p.m.	Po	7.4	2.0	2.0
	P+	24.8	28.8	10.1
Needle P, percent	Po	0.128	0.114	0.094
	P+	0.136	0.129	0.119
Needle N, percent	Po	1.39	1.40	1.41
	P+	1.39	1.38	1.32
Needle K, percent	Po	0.54	0.43	0.46
	P+	0.48	0.44	0.42
Needle Ca, percent	Po	0.235	0.295	0.220
	P+	0.247	0.287	0.228
Needle Mg, percent	Po	0.100	0.132	0.104
	P+	0.111	0.119	0.113
Needle Mn, p.p.m.	Po	177	303	167
	P+	179	274	185
Needle Al, p.p.m.	Po	678	592	485
	P+	600	686	625
Needle Cu, p.p.m.	Po	4.2	4.0	4.0
	P+	4.2	3.7	3.9
Soil N, percent	Po	0.151	0.061	0.222
Soil K, p.p.m.	Po	39	32	49
Soil Ca, p.p.m.	Po	303	180	97
Soil Mg, p.p.m.	Po	41	23	26
Soil Al, p.p.m.	Po	123	170	313
Soil pH	Po	4.7	4.5	4.5
Soil P (total), p.p.m.	Po	143	68	121
	P+	152	121	188
Soil C, percent	Po	2.64	1.56	3.83

[1]14 paired plots.
[2]10 paired plots.
[3]16 paired plots.

Comparison of Tests for Soil P

The N.C., Bray No. 2, and 5N HCl extractions were used as a series of intensities to extract acid-soluble or available P. All three solutions extract Ca-P, adsorbed P, and portions of Fe- and Al-P. Perchloric acid-H_2SO_4 digestion yields estimates of total P, although it does not extract all of the P in certain soils.

A range in P extracted was obtained by the dilute acid extractions (table 3). The correlation was high between the P extracted by the N.C. and Bray No. 2 extractants in both Coastal Plain and Piedmont soils. Phosphorus extracted by 5N HCl was well correlated with that extracted by the N. C. extractant in the Piedmont but not in the Coastal Plain. Soil organic matter was higher and organic P was also higher in the Coastal Plain than in the Piedmont, as indicated by the high correlation ($r = 0.91$) between total P and C. Because 5N HCl extracts mineral P more readily than organic P, a higher correlation was found between 5N HCl-extractable P and total P in the Piedmont than in the Coastal Plain.

Table 3.--Correlation coefficients and means and ranges for different P extractions of 60 Coastal Plain and 35 Piedmont Po (nonfertilized) soils

Extraction	Bray No. 2	5N HCl	Total P	Mean	Range
		r		p.p.m.	
COASTAL PLAIN					
N.C.	0.82*	0.32*	0.29*	3.2	0-14
Bray No. 2		.32*	.48*	5.9	1-36
5N HCl			.11	14.2	2-70
Total P				119	54-443
PIEDMONT					
N.C.	.75*	.86*	.40*	4.6	0-36
Bray No. 2		.39*	.13	8.7	2-71
5N HCl			.69*	23.1	2-267
Total P				161.8	97-506

*Significant at the 5-percent level or greater.

Phosphorus by the N.C. and Bray No. 2 extractants was correlated at the 1-percent level with height at age 3, and P extracted with 5N HCl was correlated with height at age 3 at the 5-percent level (table 1). As a predictor of response, the N.C. extractant appeared to provide better separation of plots which would respond to P fertilization than did the other extractants. This superiority was indicated by the plotted data

and by the fact that the response to P fertilization was more highly correlated with P extracted by N.C. ($r = -0.48$) than with P extracted by Bray No. 2 ($r = -0.27$), as indicated in table 1.

CONCLUSIONS

Soil P by the N.C. extractant and percentage of P in needles are useful for the prediction of loblolly pine response to P fertilization in the southeastern Coastal Plain. A lack of response to P fertilization in the Piedmont studies prevents development of guides for that region. Needle content of 0.10 percent P and values of soil P (N.C.) of 3 p.p.m. (6 lb./acre) were critical levels above which tree height at age 3 was not increased by P fertilization and below which P fertilization usually increased tree growth.

Several site factors should be considered in application of fertilization guides. In forestry operations, planting areas are relatively large, and the soil varies considerably. Variability within a plantation was demonstrated by a response to P on some replicates and no response on others within a study area of a few acres. As the trees grow older and their P requirements increase, a P response may occur on more soils and on soils with a soil-test value greater than 3 p.p.m. Competition from weeds and possibly other factors affecting growth will change as the trees become larger, and still more plots may respond to P application. Phosphorus fertilization is expected to increase growth of loblolly pine on some soils when soil P is 4 p.p.m. or less by the N.C. extractant. On the basis of these considerations, phosphorus fertilizer would be applied when soil P tests (N.C.) are 4 p.p.m. or less (8 lb./acre, assuming 2 million lb. of soil per acre in the 0- to 8-inch depth) on prepared Coastal Plain soils where growth conditions such as moisture and N supply are favorable.

The N. C. soil extractant for P compares well with the Bray No. 2 for the estimation of tree height at age 3 in the Coastal Plain. The N.C. extractant appears to provide better separation of sites where trees would respond to P fertilization than do the Bray No. 2, 5N HCl, and total-P extractions. At least eight states routinely use the N.C. extractant for soil P.[3] This uniformity offers an opportunity for improved standardization and calibration of soil tests as the use of soil testing in forestry increases.

In several paired plots, trees failed to respond to P fertilization even though soil P (N.C.) was below the critical level of 3 p.p.m. The applied P was available, as indicated by the increased P level in the needles on fertilized plots, but growth was still unsatisfactory, indicating that other limiting factors prohibited response to P.

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[3] Procedures for State soil tests may vary with respect to soil solution ratios, calculations, and the reporting of results. The N.C. test is normally made by State Soil Testing Laboratories by shaking 5 $cm.^3$ of soil and 25 ml. of extractant for 5 minutes, followed by filtering and analysis.

Nitrogen probably limited tree growth and, thus, response to P on some sites. On other sites, the lack of correlation between soil P by the tests used and the availability of soil P to trees accounts for errors in prediction of response to P fertilization. Continued study of the methodology of soil tests, tree physiology, and broader ecological relationships should produce considerable improvement in application of soils information to forest management.

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Several established studies of phosphorus fertilization in 3-year-old plantations of loblolly pine were measured for tree height and sampled for soil tests and needle analysis in order to relate soil and needle content to response to fertilization. Soil tests with the extractant adopted by the North Carolina Soil Testing Laboratories and percentage of P in needles were useful for prediction of tree response to P fertilization in the southeastern Coastal Plain but not in the Piedmont. Needle content of 0.10 percent P and values of the above-named extractant of 3 p.p.m. were critical levels above which tree height at age 3 was not increased by P fertilization and below which P fertilization usually increased tree growth. The data indicated that N influenced growth and limited response to P fertilization on some sites.

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Epidemic and Endemic Populations of the Southern Pine Beetle

by

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INTRODUCTION

The southern pine beetle, Dendroctonus frontalis Zimm. (Coleoptera: Scolytidae), an important pest of pines, destroys much timber from Pennsylvania to Texas. Epidemics of the southern pine beetle caused extensive tree mortality during the years 1920-1924, 1929-1932, and 1949-1963 (King 1972). Nicholson (1933) defines epidemic populations as those which increase faster than the factors which normally keep them in balance. Endemic populations are usually increasing at a lesser rate than those factors, but other agents, particularly favorable or adverse climatic events, affect populations of the southern pine beetle. Occasionally, a combination of environmental circumstances permits populations to increase to epidemic levels in limited portions of the species' range. Whether or not high populations require control depends more upon their location, size, and the resources threatened than the actual number of live beetles or dead trees. For example, a higher level of economic damage could be tolerated in a large coastal swamp or a national forest than in a heavily utilized recreation or scenic area or a small public park. Our purpose is to define the differences between epidemic and endemic populations in two distinctly different geographical areas (Louisiana and North Carolina) and to describe how beetle activity varies in these areas.

Vigor of Stand

The expansion or reduction of an insect population under the bark of trees is regulated by the same factors that affect aerial or soil-dwelling insects. Particularly important for bark beetles is the susceptibility of the host tree and the vigor or capacity of the beetles to colonize them (Titova 1966).

The surface tension of soil and the resulting water balance of trees and their physical state indirectly affect their susceptibility to successful beetle attacks and population potential at a given location. In Louisiana, Lorio and Hodges (1968) measured the effects of artificially induced moisture stress on oleoresin exudation pressure (OEP) and relative water content (RWC) of loblolly pines. They determined that diurnal patterns of OEP were related to changes in soil and atmospheric moisture. The RWC of inner bark reflected soil moisture stress and diameter growth response.

Craighead (1925) and Beal and Massey (1945) reported a relationship between epidemics of the southern pine beetle and prolonged (> 30 days) drought periods. In late summer and fall, moisture deficiencies appeared to be more important in predisposing trees to successful attack than those occurring during other seasons. An examination of weather records confirmed that this pattern is true only for outbreaks in North and South Carolina, particularly during years following heavy spring rains (King 1972). In Louisiana and presumably other Gulf Coast States, major outbreaks of the beetle usually follow summer droughts and heavy winter rains.

Physical and chemical conditions of the soil also affect the water balance of pines and their susceptibility to attack in another way. The Forest Atlas (Southern and Southeastern Forest Experiment Stations 1969) shows that the majority of soils in North Carolina and some in Louisiana are Ultisols. Such soils are low in organic matter, have subsurface accumulations of low-porosity clay, and become dry at some time during the growing season. Many of these Ultisols and Inceptisols in western Louisiana are occasionally flooded for extended periods and support pines with poorly developed fine root structures and mycorrhizae (Jackson and Hepting 1964).[1] As a result, soil-borne pathogens cause extensive loblolly decline and other diseases in Louisiana and neighboring states (Lorio 1966) and littleleaf disease in North Carolina. The southern pine beetle is indigenous to much of the Piedmont and related areas from North Carolina to East Texas (Southern and Southeastern Forest Experiment Stations 1969) and frequently attacks trees with littleleaf disease as well as those weakened by poor soil aeration or inadequate soil moisture. Lorio (1968) found that trees growing on mound soils in Louisiana had better aeration than those on intermound areas and were subject to less frequent attack by the beetle. In North Carolina, trees under moisture stress on dry or clay soil ridges are most susceptible to attack by bark beetles.

Hodges and Lorio (1969) found that both excessive and deficient soil moisture caused an increase in the simple sugars in stressed trees. Such sugars were the kind most usable by the southern pine beetle and its associated microorganisms and appeared more attractive to attacking adult beetles. Improved nutritional conditions of pines following periods of stress only increase the potential for attack by bark beetles (Lorio

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[1]Napier, C. J. The occurrence and seasonal variations of the fine roots and mycorrhizae of loblolly pine Pinus taeda L. in the West Bay area of Allen Parish, Louisiana. 1969. (M.S. Thesis, Northwest State Coll. La., Natchitoches, 43 pp.)

and Hodges 1968; Hodges and Lorio 1969). The success of initial attacks by the beetle was often correlated with a reduced OEP, except under very heavy epidemic populations.

Several other environmental phenomena influence the establishment and development of beetle populations; one of the foremost is lightning (Hodges and Pickard 1971). Lightning-struck trees frequently serve as initial focal points for infestation development (Hopkins 1909; Bennett 1971). Broods of emerging beetles then attack the residual green trees. Thatcher[2] found that during June, July, and August an increasing number of strikes supported generations of summer beetles in Louisiana. This followed the population explosion of spring beetles and their decline in early summer.

Stand composition also affects the population potential of the beetles. Although pure pine stands are capable of supporting larger populations because of the greater number of trees or concentrated food supply, mixed stands--a major component of the southern pine region--are frequently infested under the influence of population pressure.

In the Deep South, Bennett (1968) reported that problem areas of the southern pine beetle were characterized by poorly managed, overstocked stands where growth had dropped markedly in recent years. In North Carolina, attacks of the southern pine beetle typically begin in poorly managed stands.

Bennett (1971) stated that in second-growth forests, beetles are first attracted to injured or weakened trees and later spread through the residual stand. Beetle populations can easily go from endemic to epidemic conditions where human neglect or poor management have led to significant stand deterioration. This is particularly true where beetle-infested trees and logs or pulpwood piles are removed at intervals of several months and infested tops and unmerchantable material are left untreated, or where partial cutting is done for a year or more in the same area. In such situations, each new generation of beetles is furnished with fresh breeding material and may move to adjacent uninfested stands (Bennett 1971).

In both Louisiana and North Carolina, trees infested during the winter serve as reservoirs for carryover populations of the beetle from one season to another. Such trees may help to prolong outbreaks by harboring populations that could contribute significantly to population growth the following summer. Affecting the potential of overwintering populations to cause additional tree losses are two critical factors--winter survival, particularly in mountainous areas, and early detection of actively infested trees before broods emerge in the spring to attack new trees.

A combination of factors, both natural and man-caused, can reduce epidemic populations of the southern pine beetle to a balanced or endemic state. Cold, wet winter weather below zero F. alone, or in conjunction

[2]Thatcher, R. C. Seasonal behavior of the southern pine beetle in Central Louisiana. 1971. (Ph.D. Thesis, Auburn Univ., 102 pp.)

with insect disease, has the capacity to reduce populations (Beal 1933; Moore 1971). Moisture may also affect pheromone production and the flight of adult beetles. Removal of beetle-infested trees may also reduce the population vigor or cause emerging beetles to migrate for want of the population-aggregating pheromone.

When outbreaks of the beetle are associated with poor timber-harvesting techniques, under improved growing conditions in the cutover area, trees may become increasingly resistant and vigorous as wounds heal and resistant to insect attack in response to the thinning of the stand. In Europe, Titova (1966) found that after a 1- to 3-year period following timber harvest the trees become more resistant, leading to an increased density of existing populations of the beetle in a few trees, lower population vigor, high mortality, and, finally, a reduction in beetle population.

The dispersal or migration of beetle populations may signal a decline in insect activity or inadequate breeding material. Nicholson (1933) stated that when a population increases far above its optimum, population pressure causes shifting which decreases the chance of survival of an average individual. With Ips grandicollis, Hertel et al. (1969) determined that the greatest number of successful new attacks, 40/ft.^{2}, occurred within 360 ft. of the breeding site. From there, the number was reduced to 22/ft.^{2} at 1,320 ft. At greater distances, attack densities were much reduced. Presumably, most adults entered weak, dying trees or failed to reach susceptible hosts in sufficient numbers to overcome them. As long as weather and stand conditions are favorable to vigorous tree growth, beetle migration can limit populations and cause a return to endemic conditions. This is not the case, however, when host trees are physiologically stressed. Migrating beetles begin many small infestations, each of which may grow and spread rapidly.

Beetle Attractants

Large, aggressive populations of the southern pine beetle may become temporarily independent of the forces which normally keep them at an endemic level over a wide area (Hopkins 1909; Gara 1967; Franklin 1970). Presence or absence of secondary attacks in newly infested trees affects this pattern of dispersal behavior. Emerging populations usually remain in the area where they develop and attack infested trees when beetle emergence coincides with attractant production (Gara 1967). Adult beetles may become disoriented and disperse, however, if the most recently infested trees are removed first in a control operation, or if local weather conditions disperse the beetle attractants or significantly affect their flight. Weather may help to re-establish an endemic situation by effecting widespread dispersal of emerging beetles and heavy mortality because sufficient numbers fail to find susceptible hosts. Whether or not many small infestations develop from the dispersing beetles depends primarily upon the condition of the trees in the area, the number and physical condition of the beetles, and the season of the year. A lack of susceptible host material may lower attractant production or reduce the number of beetles, which results in poor response capability (Gara 1967).

Competition and Emergence Patterns

In healthy populations of the southern pine beetle, there may be two emergence peaks for adults in some generations. Some attacking parent females emerge approximately 2 weeks after depositing their eggs and establish a second brood; teneral adults emerge at least 10 days later (Franklin 1970). During the years 1967-1968, evidence of this was found in North Carolina and has also been observed in Texas and Louisiana.

Endemic Populations

During the growing season the occurrence of only a few single or small infestations scattered over extensive areas indicates a low population level. In such situations, one or more Ips species occupies the upper two-thirds of the bole, D. frontalis the lower midbole, and D. terebrans the base, thus limiting the space for establishment and development of broods of D. frontalis. In extreme situations, populations of D. frontalis are limited to a few feet of trunk and may be clearly secondary to other bark beetles, depending upon the sequence of attack. Ips species may be the only bark beetle occupants of an outer ring of newly attacked trees.

Seasonal Weather Variations, Biological Regulators, and Other Influences

Because there is a population fluctuation of the southern pine beetle from winter to summer, or during the summer, we could easily assume that a measurable population change is taking place. This is not necessarily so. Based on present technology, we know that the complex interactions, adverse weather, soils, stand and tree conditions, and associated insect activity, are often unpredictable.

In Louisiana, up to 85 percent more adults emerged in early spring and late fall than during the summer months of 1964-1967.[3] This was partly due to greater length of infested stem and higher brood survival. Brood adults were generally larger and presumably more vigorous. Interspecific competition with other bark beetles and wood borers was generally reduced. By contrast, summer-produced beetles were smaller, had a lower fat content, and were less vigorous. Where developmental conditions were more adverse, many of the latter beetles developed in exposed inner bark portions, as evidenced by abnormally long larval mines and poor survival. Such broods were also exposed to extreme competition with other inhabitants of the inner bark and were more vulnerable to many parasites and predators.[4]

In North Carolina, brood development and survival were considerably different. Emergence in summer and fall averaged 14 percent higher than that in trees occupied by overwintering populations. In such

[3] Ibid.
[4] Ibid.

northerly states, winters were more severe and summers milder than in Louisiana. Incidence of disease was higher and frequently followed near- or sub-zero weather.

Several investigators have demonstrated that temperature extremes affect beetle activity and survival (Hopkins 1899; Craighead 1925; Beal 1933; Franklin 1970; Moore 1971, 1972). At 15° C., newly emerged adults may live in the laboratory for 30 days, but survival drops to 12 days at 30° C. (Moore 1973). When daytime temperatures exceed 38° C. for several days, brood development and survival are markedly reduced. A 2-hour exposure to 44° C. is fatal to all life stages (Beal 1933).

At the other extreme, flight activity is inhibited when temperatures drop below 10° C. (Franklin 1970). This explains the minimal number of newly attacked trees and limited expansion of existing infestations in the winter or early spring in South Atlantic or Gulf Coast States. When temperatures drop below -20° C., severe to total brood mortality results, depending, in part, on condition of host and bark thickness.

Although moisture and temperature conditions may not be severe enough to cause direct mortality, they may weaken the population and make the brood more susceptible to diseases of pathogenic bacteria and fungi (Moore 1971). A case in point was the rapid decline of the outbreak in West Virginia in 1893 following cold, wet weather and a marked increase in disease incidence (Hopkins 1899).

To maintain a stable or balanced state, some control factors must act more severely against the insects when their density is high and less severely when their density is low (Nicholson 1933). In North Carolina this was the case with the southern pine beetle from 1966 to 1969. Figure 1 shows the total potential population of beetles (16 consecutive generations) from 1966 to 1969, and below that potential, the actual number that escaped predation, parasitism, and disease and emerged as adults. The density of live beetles was 13.5/ft.^{2} in 1966 and rose to 67.6/ft.^{2} in 1969; as density increased, the percentage surviving decreased from 52 to 47. The cyclic population curve for the southern pine beetle was inversely proportional to that showing losses from disease (fig. 2). Moore (1972) found that the red-bellied clerid and the downy woodpecker showed a density-dependent response to populations of the southern pine beetle. Other agents, parasites, and disease removed a quantity of brood that varied out of proportion with shifts in the beetle population. From 1966 to 1969, however, the quantity removed and all parasites and predators generally increased along with the population of bark beetles (fig. 2). Because of interspecific competition, Nicholson (1933) believed that a steady state was practically impossible when several species of specific parasites simultaneously attacked a common host species. This parasitoid complex is the case with the southern pine beetle and is one of the reasons that populations fluctuate as they do. Beaver (1967) stated that parasites and woodpeckers have threshold densities below which they are ineffective, but the levels vary with environmental conditions, such as availability of alternative hosts and food. Moore (1972) found this was true with the

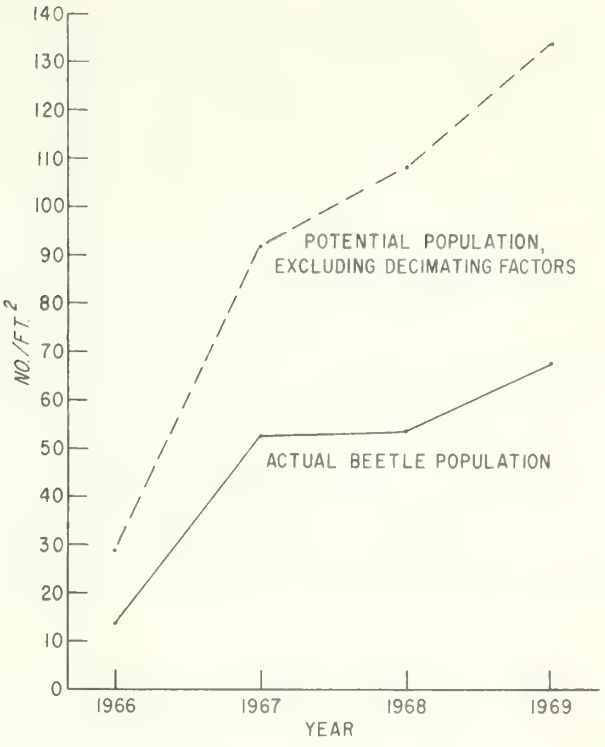

Figure 1.--Potential population of the southern pine beetle and actual number escaping parasitism, predation, and disease in North Carolina from 1966 to 1969.

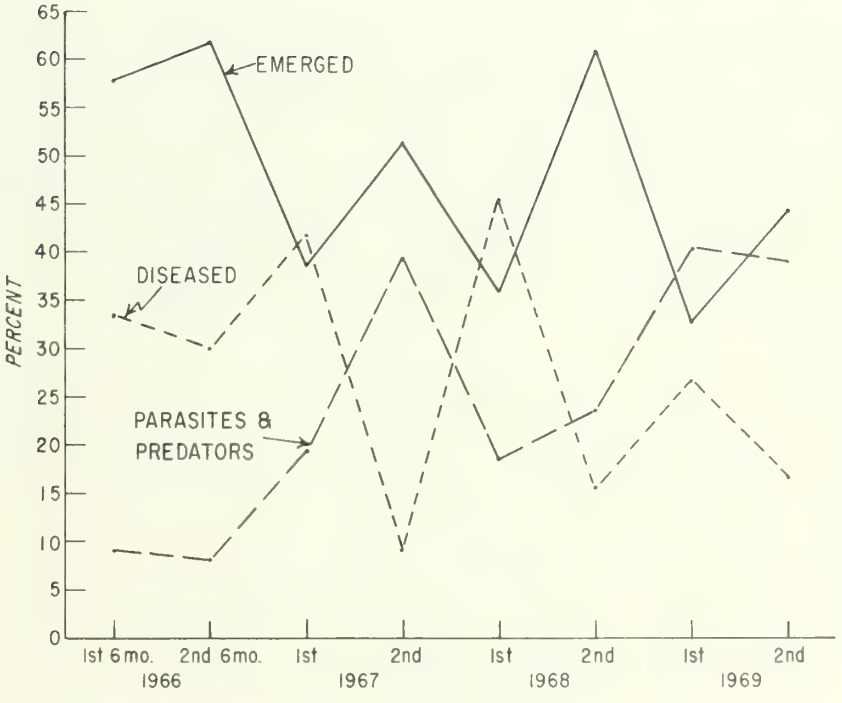

Figure 2.--Percentage of emergence of southern pine beetles and those destroyed by parasites, predators, and disease in North Carolina from 1966 to 1969.

downy woodpecker. During the summer months when other food was available, woodpeckers removed only 2 percent of the brood; in fall and winter they removed as much as 12 percent.

Prevention and Control of Recurring Epidemics

Because outbreaks of the beetle often begin in water-stressed, slow-growing stands, forest management strategies should attempt to optimize growing conditions over the length of a normal cutting rotation. Cultural techniques are needed that will stimulate growth. In addition, more attention should be given to the selection of species adapted for particular sites. Stands should be thinned periodically to maintain them at densities which the respective sites can support and which favor desired radial growth rates throughout the rotation cycle of the stand. Selective removal of trees in advanced decline and early detection and removal of lightning-struck trees containing beetle brood should reduce the number of sites from which southern pine beetles are likely to spread.

Unfavorable conditions for the multiplication of broods of the southern pine beetle are usually found in areas where mature timber is removed with minimal damage to the residual stand and where timber harvesting practices are scheduled to encourage the vigorous radial growth of the remaining trees (Hopkins 1909; Bennett 1971).

Destruction of 50 to 70 percent of the beetles usually reduces beetle populations from epidemic to endemic status (Hopkins 1909). Because natural mortality usually reduces from 45 to 55 percent of the beetle population (Moore 1972), satisfactory control could be accomplished by manipulating an additional 20 to 30 percent of the population through increased levels of control of selected predators, parasites, or pathogens. Selective removal of beetle-infested trees, limited application of pesticides, utilization of natural or synthetic attractants, and timely cultural practices would favor natural control at the expense of beetle populations.

CONCLUSIONS

Factors that favor epidemic populations of beetles are:

1. Prolonged moisture stress in trees.

2. Slow growth of trees and dense stand conditions.

3. Poor internal drainage and low fertility of soil.

4. Excessive damage to residual stands during timber harvest or other cultural operations.

Factors that favor endemic populations or a return to balance are:

1. Weather conditions that favor long-term, improved growth of trees and resistance to attacking beetles by causing mortality of beetles in flight or in trees, or by encouraging the development of pathogenic organisms.

2. High-density populations of the southern pine beetle that favor intraspecific or interspecific competition with other species of bark beetles.

3. Production of natural attractants out of phase with emerging brood adults that leads to dispersal and subsequent potential mortality of beetle populations.

Because the southern pine beetle behaves differently in the Piedmont and Southern Appalachian Mountains of North Carolina than it does in the Deep South, generalizations about beetle populations and management principles should not be the same for the entire region.

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Estimating Veneer and Residual Pulpwood Volumes for Planted Slash Pine Trees

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The softwood plywood industry entered the South in 1964 with three plants in Arkansas accounting for 0.7 percent of U.S. production. By 1968, 34 plants in the region accounted for 18.4 percent of the total U.S. production.[1] This growing industry now competes for large volumes of raw materials, and these demands increasingly will be satisfied from southern pine plantations.

This paper reports estimates of the number of 2 by 4 studs from cores, veneer volume, and residual pulpwood volume realizable from planted slash pine trees of various sizes (§6 and §7). These estimates were derived by

constructing inside and outside bark taper curves for planted slash pine trees (§1 and §2),

predicting from the inside bark taper curves and simple geometry the number and the gross volume of veneer blocks (§3),

estimating the proportional losses in peeling, and consequently the net volume of the blocks (§4), and

computing the residual pulpwood volume from the outside bark taper curves (§5 and Appendix 2).

A list of symbols used is given in Appendix 1.

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[1] Lambert, Herbert G. Plywood production sets record as '68 marks dramatic turnabout. For. Ind. 96(1): 41-49. 1969.

§1 INSIDE BARK TAPER CURVES

The inside bark taper of planted slash pine trees has been described[2] as follows:

$$\widehat{d(h)} = \frac{.8544\ D[H-h]}{H-4.5} + .002988[H-h][h-4.5] - .00004822\,H[H-h][h-4.5] + .00001938[H-h][h-4.5][H+h+4.5] \qquad (1.1)$$

where D = diameter outside bark at breast height (in inches),

H = total height (in feet), and

$\widehat{d(h)}$ = the estimated diameter inside bark (in inches) at any height, h (in feet), above the ground satisfying $4.5' \le h \le H$.

The form of equation (1.1) derives basically from three assumptions:[3]

1) diameter inside bark above breast height is approximated by a third-degree polynomial of height above ground; i.e., $d(h)$ is approximated by a cubic equation in h,

2) diameter inside bark at breast height is approximately a constant proportion of diameter outside bark at breast height; i.e., $d(4.5) = kD$ approximately, and

3) diameter inside bark at the top of the tree is zero; i.e., $d(H) = 0$.

The coefficients in (1.1) were estimated from inside bark diameters measured at 4-foot intervals on 136 sample trees collected throughout the Middle Coastal Plain of Georgia and in Duval County in northeast Florida. Diameters of sample trees ranged from 8 to 18 inches, heights from 40 to 95 feet, ages from 10 to 36 years, and plantation spacing ranged from 6 by 6 to 18 by 20 feet. Equation (1.1) fitted these data with a coefficient of determination (R^2) of .9962 and a standard error of 0.49 inch.

§2 OUTSIDE BARK TAPER CURVES

We have now fitted an equation of the form of (1.1) to the outside bark diameters of the trees described in §1. Denoting the outside bark diameter at height h by $D(h)$ to distinguish it from the inside bark diameter, $d(h)$, the resulting outside bark taper curve is

$$\widehat{D(h)} = \frac{D[H-h]}{H-4.5} + .003590[H-h][h-4.5] - .00007700\,H[H-h][h-4.5] + .00003320[H-h][h-4.5][H+h+4.5] \qquad (2.1)$$

where, as before, $4.5' \le h \le H$.

---

[2] Bennett, Frank A., and Swindel, Benee F. Taper curves for planted slash pine. Southeast. For. Exp. Stn., USDA For. Serv. Res. Note SE-179, 4 pp. 1972.

[3] We implicitly assume throughout the paper that tree cross sections are circular.

This equation fits the sample data with a standard error of 0.49 inch. As another indication of the fit of (2.1), 101 of the 136 sample trees are fitted by (2.1) with no residual as large as 1 inch.

It will be noticed that (2.1) necessarily has properties analogous to properties 1), 2), and 3) in §1 that were required of the inside bark curve. But (2.1) is not proportional to (1.1). We tested the hypothesis that the inside and outside bark diameters are proportional throughout the length of the stem, and that hypothesis had to be rejected.

§3 PREDICTION OF GROSS VENEER VOLUMES OF INDIVIDUAL BLOCKS

The points in figure 1 represent the observed volumes (in cubic feet) of grade "D" or better veneer for 245 peeler blocks from 39 nonturpentined slash pine trees selected from natural stands[4] near Waycross, Georgia, in 1971 and peeled in the U.S. Plywood plant in Hammond, Louisiana. This scatter graph shows that observed volume is a moderately tight function of scaling diameter, but the relation is nonlinear with a negative intercept. Consequently, if the measured volumes are simply regressed on scaling diameter, several regression parameters must be estimated from the data. Moreover, there is no a priori guarantee that such an empirical relation would satisfy certain computable constraints near the edge or beyond the range of the data.

An alternative approach is used here. It requires separate consideration of the maximum possible volume (hereafter called gross volume) that can be realized from peeler blocks of a particular scaling diameter, and the actual volume (hereafter called net volume) that is observed.

Let V denote gross volume (in cubic feet) ignoring fishtails; i.e., ignoring losses in roundup. From simple geometrical considerations, V is a function of

L = the length of the block (in feet),

τ = the thickness of ply cut (in inches),

δ = the core diameter (in inches), and

d = the scaling diameter (in inches).

In fact, if the cut plies are thin, then a good approximation (as we will see) to V is

$$V \simeq \frac{\pi L}{(4)(144)} \{[d-\tau]^2 - [\delta+\tau]^2\} . \qquad (3.1)$$

[4] We assume that peeler blocks from plantations, with the same scaling diameters as these blocks, would produce similar veneer volumes.

In particular, if

i) the spur knives are 102 inches apart,

ii) the dried ply is to be 0.1 inch thick, and

iii) two 2 by 4 studs are cut from each core

(this was the operational setup in our study), then for all peeler blocks we would expect (approximately)

$$L = 8.5 \text{ feet},$$

$$\tau = 0.104 \text{ inch, and} \qquad (3.2)$$

$$\delta = 5.4 \text{ inches}.$$

Substituting (3.2) into (3.1) gives

$$V \simeq .04636\, d^2 - .00964\, d - 1.40393 \qquad (3.3)$$

as a potential predictor of gross volume under the circumstances of i), ii), and iii). Apparently, (3.3) does provide a good approximation to

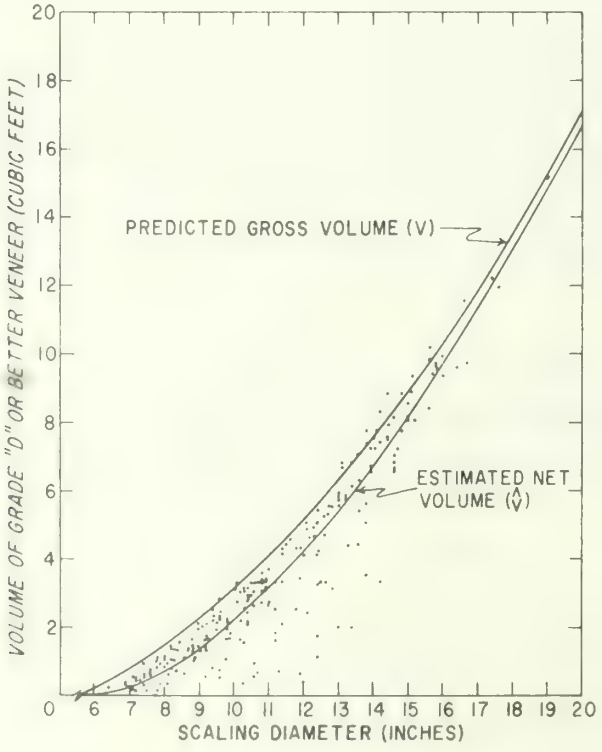

Figure 1.--Volume of grade "D" or better veneer of 245 slash pine peeler blocks.

gross volume. It is the upper curve plotted against the slash pine data[5] in figure 1.

§4 ESTIMATION OF NET VENEER VOLUMES OF INDIVIDUAL BLOCKS

The net volumes of individual blocks should be, and apparently are, smaller than the gross volumes, V, predicted by (3.3) because there typically are inefficiencies in using the blocks and deductions for below-grade material and for various defects. What we require from the data is an estimator of these deficiencies or losses sustained in peeling the block.

If the net volume is denoted by v and the various losses in peeling by Δ, then

$$\Delta = V - v. \tag{4.1}$$

As one would expect, the losses, Δ, are not easily predicted. Still, when the proportional losses, Δ/V, are plotted against scaling diameter, d, an exponential relation

$$\frac{\Delta}{V} = e^{\alpha[d-5.608]}, \qquad 5.608'' \leq d \tag{4.2}$$

is clearly suggested. Note that acceptance of (4.2), with α negative, would imply that the losses ought never (aside from measurement errors) be negative, and that the proportional losses decline exponentially from one (at d = 5.608") to zero as scaling diameter increases. These properties are consistent with our data and intuition. So, we fitted (4.2) to our data and obtained

$$\frac{\hat{\Delta}}{V} = e^{-.275[d-5.608]}, \qquad 5.608'' \leq d. \tag{4.3}$$

---

[5]Note that (3.3) is not derived empirically from any volume data; i.e., there are no estimated parameters in that equation. Rather, it is derived from the operational constraints in i), ii), and iii). We can note that observations made on the slash pine are consistent with these constraints as they are reflected in (3.2), except that five of the original 250 blocks had large (6.2" - 8.4") cores--possibly due to slippage of the chucks. In any event, these five blocks were omitted in all our computations with the slash pine data. The resulting histograms for L and δ were

L	
8.50'	2
8.55'	43
8.60'	67
8.65'	68
8.70'	42
8.75'	18
8.80'	4
8.85'	0
8.90'	1
	245

δ	
5.2"	1
5.3"	2
5.4"	38
5.5"	22
5.6"	152
5.7"	22
5.8"	7
5.9"	1
	245

This we consider to be good agreement with the theoretical constraints in (3.2).

Given this estimator of proportional loss, an estimator, $\hat{v}$, of net volume is available

$$\hat{v} = V - \hat{\Delta} = V\left\{1 - \frac{\hat{\Delta}}{V}\right\} = V\left\{1 - e^{-.275[d-5.608]}\right\}, \qquad 5.608'' \leq d. \quad (4.4)$$

Equation (4.4) is plotted against our data as the lower curve in figure 1. Although it is a one-parameter curve, it fits the observed data well. And, it necessarily has desirable properties in that it predicts zero net volume just at the theoretical minimum scaling diameter and it is necessarily never above the predictor of gross volume.

§5 COMPUTATION OF VENEER AND RESIDUAL PULPWOOD VOLUMES FOR A TREE OF GIVEN SIZE: AN EXAMPLE

Equations (1.1), (2.1), (3.3), and (4.4) constitute a mechanism for estimating the veneer and residual pulpwood volumes of planted slash pine trees of arbitrary diameter (outside bark at breast height) and total height. It is only necessary to specify

s = height of stump (in feet),

t = trim allowance for peeler blocks (in feet),

M = merchantability limit for peeler blocks (inside bark in inches),

m = merchantability limit for pulpwood bolts (outside bark in inches), and

ℓ = length of pulpwood bolts (in feet).

For the sake of illustration let us take[6]

$s = 0.5$ foot,

$t = 0.15$ foot,

$M = 7.95$ inches, (5.1)

$m = 3.95$ inches, and

$\ell = 5.25$ feet

and compute the estimated volume for a tree with

$D = 12.0$ inches, and

$H = 65.0$ feet.

[6] Note that we have taken the merchantability limits here to be the 8.0-inch class and the 4.0-inch class when diameters are measured to the nearest 0.1 inch. Other users may, of course, construct merchantability limits by a different rationale.

From (1.1) the estimated diameters inside bark at height h = 9.15, 17.80, 26.45, and 35.10 feet (i.e., the estimated scaling diameters of the first four veneer blocks) are

$$\widehat{d(9.15)} = 9.823 \text{ inches},$$

$$\widehat{d(17.80)} = 8.969 \text{ inches},$$

$$\widehat{d(26.45)} = 7.983 \text{ inches, and}$$

$$\widehat{d(35.10)} = 6.788 \text{ inches},$$

respectively. The last diameter is below the specified merchantability limit for veneer blocks, so we expect the tree to have three merchantable blocks with scaling diameters estimated to be 9.823, 8.969, and 7.983 inches, respectively.

From (3.3) the gross volumes of blocks this size are predicted to be

$$V = .04636[9.823]^2 - .00964[9.823] - 1.40393 = 2.97,$$

$$V = .04636[8.969]^2 - .00964[8.969] - 1.40393 = 2.24, \text{ and}$$

$$V = .04636[7.983]^2 - .00964[7.983] - 1.40393 = 1.47$$

cubic feet, respectively. From (4.4) the net volumes are estimated to be

$$\hat{v} = 2.97\{1-e^{-.275[9.823-5.608]}\} = 2.04,$$

$$\hat{v} = 2.24\{1-e^{-.275[8.969-5.608]}\} = 1.35, \text{ and}$$

$$\hat{v} = 1.47\{1-e^{-.275[7.983-5.608]}\} = 0.71$$

cubic feet, respectively. The net veneer volume of the tree is estimated to be 4.10 cubic feet.

From equation (2.1) the diameters outside bark at the small end of the six successive pulpwood bolts immediately above 26.45 feet are estimated to be

$$\widehat{D(31.70)} = 8.37 \text{ inches},$$

...

$$\widehat{D(52.70)} = 4.01 \text{ inches, and}$$

$$\widehat{D(57.95)} = 2.46 \text{ inches},$$

respectively. The last diameter is below the specified merchantability limit for pulpwood bolts, so we expect the tree to have five merchantable

pulpwood bolts between the lower limit, say h_*, and the upper limit, say h^*, of pulpwood utilization; that is, between

$h_* = 26.45$ feet and

$h^* = 52.70$ feet.

Assuming as we have that tree cross sections are circular,[3] estimates of the volume of the stem, including bark, between arbitrary points h_* and h^*, such that $4.5' \leq h_* \leq h^* \leq H$, can be obtained as a solid of revolution from the outside bark taper curve (i.e., (2.1)). In fact, the resulting explicit volume equation, which is a function of h_*, h^*, D, and H, is derived in Appendix 2. It appears as equation (A.8) where the coefficients R_0, R_1, R_2, and R_3 are defined in (A.4) through (A.7), respectively. For the example tree with D = 12.0 inches and H = 65.0 feet it can be verified that

$R_0 = 6.315767$,

$R_1 = -0.073018$,

$R_2 = 0.0007075$, and

$R_3 = -0.00001660$.

Solving (A.8) with these coefficients, we find that the estimated pulpwood volume in the tree is 7.06 cubic feet.

§6 VENEER AND RESIDUAL PULPWOOD VOLUME TABLE: AN EXAMPLE

Assuming utilization parameters as in (5.1), we have computed estimates of the volume of primary products for a range of diameters, D, and heights, H, in table 1. The entries in the cells of the table are the estimated number of veneer blocks, the estimated net volume of 0.1-inch veneer (in cubic feet), the estimated number of pulpwood bolts, and the estimated pulpwood volume (in cubic feet). The estimated number of 2 by 4 studs that can be cut from the cores is just twice the estimated number of veneer blocks.

Note that in the first two cells of table 1 the predictor of pulpwood volume fails simply because the "residual" stem is the entire stem and our taper curve (2.1) does not fit well below breast height.

[3] See footnote 3 on page 2.

Table 1.--Estimated volume of veneer and residual pulpwood for planted slash pine trees

Diameter (inches)	Height (feet)										
	40	45	50	55	60	65	70	75	80	85	90
10	0-0.00	0-0.00	1-0.72 5-7.52	1- 0.78 6- 9.12	1- 0.83 7-10.78	1- 0.86 8-12.49	1- 0.89 8-13.66	1- 0.90 9-15.42	2- 1.61 9-13.48		
11		1-1.12 4-7.09	1-1.21 5-8.88	1- 1.29 6-10.74	2- 2.12 5- 7.84	2- 2.29 6- 9.72	2- 2.43 7-11.65	3- 3.24 6- 9.26	3- 3.42 7-11.15	3- 3.54 8-13.03	
12			2-2.58 4-5.75	2- 2.90 4- 6.99	2- 3.17 5- 9.03	3- 4.10 5- 7.06	3- 4.47 5- 8.42	3- 4.78 6-10.51	4- 5.77 6- 8.82	4- 6.09 7-10.82	
13				2- 4.05 5- 8.67	3- 5.14 4- 5.92	3- 5.70 5- 7.96	3- 6.16 6-10.16	4- 7.39 5- 7.69	4- 7.92 6- 9.83	5- 9.08 5- 7.62	
14					3- 6.83 4- 6.65	3- 7.50 5- 8.93	4- 8.91 4- 6.32	4- 9.68 5- 8.54	5-11.06 4- 6.23	5-11.84 5- 8.40	6-13.12 4- 6.25
15						4-10.23 3- 4.78	4-11.29 4- 6.99	4-12.21 5- 9.43	5-13.95 4- 6.83	5-14.88 5- 9.20	6-16.51 5- 7.47
16							4-13.89 4- 7.69	5-15.79 3- 5.11	5-17.10 4- 7.47	6-18.96 4- 5.82	6-20.19 5- 8.10
17							4-16.68 4- 8.43	5-18.98 4- 6.28	5-20.47 4- 8.13	6-22.71 4- 6.30	6-24.14 5- 8.75

LEGEND

number of blocks -- veneer volume (cubic feet)

number of bolts -- pulpwood volume (cubic feet)

Notes: Estimated number of 2 by 4 studs from cores is 2 (estimated number of veneer blocks).

Utilization parameters assumed here: s = 0.5 foot, t = 0.15 foot, M = 7.95 inches, m = 3.95 inches, and ℓ = 5.25 feet.

§7 OTHER VOLUME TABLES AVAILABLE

Table 1 is printed for diameters ranging from 10 to 17 inches by 1-inch increments, and for heights ranging from 40 to 90 feet by 5-foot increments, i.e., for

$$D = 10(1)\ 17, \text{ and}$$
$$H = 40(5)\ 90, \tag{7.1}$$

with deletions in the corner cells where we had insufficient data. Moreover, it is based explicitly upon the utilization parameters in (5.1).

We can print, for anyone wishing them, more or less comprehensive tables based on alternative utilization parameters; i.e., we can print tables for alternative values of (5.1) and (7.1).

Landowners may wish to specify ℓ small, say 0.1 foot. In that case the tabulated pulpwood volume approximates the residual pulpwood volume to the specified merchantability limit (m) ignoring utilization considerations.

§8 APPENDIX 1: LIST OF SYMBOLS

α = a parameter indicative of peeling losses (to be estimated from the data).

δ = diameter (in inches) of the core of veneer blocks.

Δ = losses (in cubic feet) incurred in peeling veneer blocks, i.e., gross minus net volume (V-v).

d = scaling diameter (in inches) of veneer blocks.

d(h) = diameter inside bark (in inches) at height, h, above the ground.

D = diameter outside bark (in inches) at breast height.

D(h) = diameter outside bark (in inches) at height, h, above the ground.

h = height (in feet) above the ground of an arbitrary point on the stem above breast height. In particular, h_* and h^* denote lower and upper limits of pulpwood utilization, respectively.

H = total height (in feet) of a tree.

k = a proportionality constant = d(4.5)/D.

ℓ = length (in feet) of pulpwood bolts.

L = length (in feet) of veneer blocks not counting trim allowance.

m = merchantability limit outside bark (in inches) for pulpwood bolts.

M = merchantability limit inside bark (in inches) for veneer blocks.

R^2 = coefficient of determination = square of multiple correlation coefficient.

R_i = coefficient in volume equation, a function of D and H (i=0, 1, 2, 3).

s = stump height (in feet).

t = trim allowance (in feet) for veneer blocks.

τ = thickness (in inches) of cut plies.

v = net veneer volume (in cubic feet).

V = gross veneer volume (in cubic feet).

§9 APPENDIX 2: EXPLICIT VOLUME EQUATIONS FOR RESIDUAL PULPWOOD

From equation (2.1) the radii outside bark (in inches) above breast height of a slash pine tree are well estimated by a cubic equation in height above ground; i.e., $4.5' \le h \le H$ implies

$$\widehat{R(h)} = \frac{1}{2}\widehat{D(h)} = \frac{D[H-h]}{2[H-4.5]} + .001795[H-h][h-4.5]$$
$$- .00003850\,H[H-h][h-4.5] \qquad (A.1)$$
$$+ .00001660[H-h][h-4.5][H+h+4.5] .$$

It is convenient now to write this equation explicitly as a third-degree polynomial in h; i.e., as

$$\widehat{R(h)} = R_0 + R_1 h + R_2 h^2 + R_3 h^3 \qquad (A.2)$$

and to find the coefficients R_0, R_1, R_2, and R_3 as explicit functions of D and H.

Rewriting (A.1) and collecting terms, we have

$$\widehat{R(h)} = \frac{DH}{2[H-4.5]} - \frac{Dh}{2[H-4.5]} - (.001795)h^2$$
$$+ (.001795)(H+4.5)h - (.001795)(4.5)(H) + (.00003850)(H)h^2$$
$$- (.00003850)(H)(H+4.5)h + (.00003850)(4.5)(H^2)$$
$$- (.00001660)h^3 + (.00001660)(H^2+4.5H+(4.5)^2)h$$
$$- (.00001660)(4.5)(H)(H+4.5)$$
$$= \left[\frac{DH}{2(H-4.5)} - (.001795)(4.5)(H) + (.00003850)(4.5)(H^2)\right.$$
$$\left. - (.00001660)(4.5)(H)(H+4.5)\right]$$
$$+ \left[\frac{-D}{2(H-4.5)} + (.001795)(H+4.5) - (.00003850)(H)(H+4.5)\right.$$
$$\left. + (.00001660)(H^2+4.5H+(4.5)^2)\right]h$$
$$+ \left[-.001795 + (.00003850)(H)\right]h^2 + \left[-.00001660\right]h^3 . \qquad (A.3)$$

Comparison of (A.2) and (A.3) shows that

$$R_0 = \frac{DH}{2(H-4.5)} + [-(.001795)(4.5) - (.00001660)(4.5)^2]H$$

$$+ [(.00003850)(4.5) - (.00001660)(4.5)]H^2$$

$$= \frac{DH}{2(H-4.5)} - .00841365H + .00009855H^2 , \qquad (A.4)$$

$$R_1 = \frac{-D}{2(H-4.5)} + [(.001795)(4.5) + (.00001660)(4.5)^2]$$

$$+ [.001795 - (.00003850)(4.5) + (.00001660)(4.5)]H$$

$$+ [-.00003850 + .00001660]H^2$$

$$= \frac{-D}{2(H-4.5)} + .00841365 + .00169645H - .00002190H^2 , \qquad (A.5)$$

$$R_2 = -.001795 + .00003850H, \text{ and} \qquad (A.6)$$

$$R_3 = -.00001660. \qquad (A.7)$$

Now, assuming (as we have) that stems have circular cross sections, the estimated volume of the stem between two arbitrary points, say h_* and h^* such that $4.5' \le h_* \le h^* \le H$, can be computed from (A.2) as a solid of revolution. From elementary calculus that volume in cubic feet is

$$V_{h_*}^{h^*} = \frac{\pi}{144} \int_{h_*}^{h^*} \widehat{[R(h)]}^2 \, dh$$

$$= \frac{\pi}{144} \int_{h_*}^{h^*} [R_0 + R_1 h + R_2 h^2 + R_3 h^3]^2 dh$$

$$= \frac{\pi}{144} \int_{h_*}^{h^*} \{R_0^2 + 2R_0R_1h + (R_1^2 + 2R_0R_2)h^2 + (2R_0R_3 + 2R_1R_2)h^3$$

$$+ (R_2^2 + 2R_1R_3)h^4 + 2R_2R_3h^5 + R_3^2h^6\} \, dh$$

$$= \frac{\pi}{144} \left[R_0^2 h + R_0R_1h^2 + \frac{1}{3}(R_1^2 + 2R_0R_2)h^3 + \frac{1}{2}(R_0R_3 + R_1R_2)h^4 \right.$$

$$\left. + \frac{1}{5}(R_2^2 + 2R_1R_3)h^5 + \frac{1}{3}R_2R_3h^6 + \frac{1}{7}R_3^2 h^7 \right]_{h_*}^{h^*} .$$

Thus,

$$V_{h_*}^{h^*} = \frac{\pi}{144} \left[R_0^2(h^* - h_*) + R_0R_1(h^{*2} - h_*^2) + \frac{1}{3}(R_1^2 + 2R_0R_2)(h^{*3} - h_*^3) \right.$$

$$+ \frac{1}{2}(R_0R_3 + R_1R_2)(h^{*4} - h_*^4) + \frac{1}{5}(R_2^2 + 2R_1R_3)(h^{*5} - h_*^5)$$

$$\left. + \frac{1}{3} R_2R_3(h^{*6} - h_*^6) + \frac{1}{7} R_3^2(h^{*7} - h_*^7) \right] . \qquad \text{(A.8)}$$

Equation (A.8) is the desired explicit equation for the estimated topwood volume in cubic feet.

Bennett, Frank A., Swindel, Benee F., and
Schroeder, James G.
1974. Estimating veneer and residual pulpwood volumes for planted slash pine trees. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-112, 14 pp.

This paper reports estimates of the volumes of planted slash pine trees. Estimates of the number of 2 by 4 studs from cores, veneer volume, and residual pulpwood volume for trees of various diameters and heights are tabulated. Tables are available upon request for utilization limits other than those assumed in the paper. For slash pine plantations and given utilization standards, these tables are useful for predicting the outturn of all the primary products of peeler trees of a given diameter and height.

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Comparative Effects of Brick and Wood Siding on the Moisture Conditions in Wood Walls

by
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INTRODUCTION

Brick veneer is a widely used siding material in residential construction, especially in the Southern and Southeastern areas of the United States. Although the use of brick veneer as a siding material with wood-frame walls appears to be a durable combination, questions have been asked about the effects of the brick on the moisture conditions in the wood frame. Does the brick veneer cause moisture conditions in the wood wall to differ from those in a similar wall with conventional wood siding?

Much of the interest in the effects of the brick veneer on wall moisture stems from the position of the brick-veneer footings. When the brick veneer is constructed over a wood-frame wall, the footings are usually below grade, especially in the South. In addition, the brick is laid about 1 inch away from the main foundation and the exterior wall sheathing. Because this air cavity between the bricks and the sheathing is partly below grade, it could provide a route for moisture vapor from the brick-veneer footings. The moisture could move up this cavity and be absorbed by the exterior sheathing, thus causing moisture conditions to be higher than normal in the wood-frame wall. These conditions can be influenced considerably by construction details at the top of the brick wall, because such details affect venting in the cavity.

The movement of moisture vapor from the air cavity into the wood-frame wall depends on the time of the year and on the nature of the overall vapor pressure gradient that exists across the wood-frame and brick-veneer wall combination. During the winter when the exterior temperature is below that of the interior environment because of winter heating, the vapor pressure gradient created across the exterior wall results in movement of moisture vapor from inside the structure through the wall section and into the exterior environment. This pressure gradient exists across walls sided with brick and wood alike. During the summer, when the exterior temperature is higher than the interior temperature because of air conditioning, the vapor pressure gradient across the exterior wall tends to move moisture vapor into the structure.

Thus, during the winter when the direction of the vapor flow is toward the outside environment, the problem of the excess moisture vapor in the cavity would be of little concern, because it would not significantly penetrate the sheathing and wall insulation. However, during summer air conditioning, the moisture in the cavity might flow into the wood-frame wall under the influence of the vapor pressure gradient, thus increasing the moisture content of the wood structural members of the wall section.

The presence and position of the vapor barrier in the wall also has an effect on the amount of moisture flow through the wall. Traditionally, the vapor barrier is placed on the interior side of the insulation to minimize moisture condensation during winter. However, the interior position of the barrier could cause an unnecessary moisture accumulation during summer air conditioning, especially if the cavity between the bricks and the wall sheathing were to serve as a source of moisture vapor. Moisture vapor that migrates through the sheathing into the wall increases the relative humidity in the wall because of the nature of the decreasing temperature gradient. The presence of the interior vapor barrier could cause the moisture to accumulate, thus increasing the overall moisture conditions in the wall. In extreme cases, the high moisture conditions would increase the hazards of mold, mildew, and wood decay because the temperatures in the wall during summer air conditioning are in a suitable range to promote activity of microorganisms.

This study was undertaken to determine if moist conditions exist in the cavity between bricks and sheathing, and if so, what effect this moisture has on the moisture profiles through insulated wood-frame walls with an exterior brick veneer. For comparative purposes, moisture profiles were determined at the same time in adjacent walls with conventional, beveled wood siding. Both types of walls contained panels with and without vapor barriers in order to determine whether such barriers affected moisture conditions in the two walls under winter heating and summer air conditioning.

MATERIALS AND METHODS

Environmental Exposure Study

This study was conducted at the Southeastern Forest Experiment Station's Whitehall environmental structure in Athens, Georgia (fig. 1). The structure is located in an open area, without trees or other protection, on a gently sloping site that is well drained. This 24- by 24-foot structure is of post-and-beam construction and is so designed that individual wall panels can be prefabricated to various construction requirements and inserted into modular spaces in the walls. In the original structure, a conventional concrete ledge was provided beneath the concrete foundation, below grade level, so that a conventional brick-veneer facing could be installed later (fig. 2).

Figure 1.--Whitehall environmental exposure structure at Athens, Georgia. Note the brick veneer on the corner section.

In the present study, such a brick wall was installed on this ledge by a commercial bricklayer. Metal ties that are normally used in brick-veneer construction were omitted. For economy and simplicity, these brick panels were laid up at each of two opposite corners, so that, at each corner, a brick section faced in two of the four cardinal directions. A metal fascia cap was placed at the top of the brick-veneered wall and fastened to the wood structure to close this space tightly, but the space was not sealed. This arrangement was intended to simulate typical conditions when a wood fascia board is installed at the top of a brick-veneered wall. The two wall sections at each corner were separated by vertical wood strips and sealed against the corner post so that the cavities between the two 4-foot brick sections would be separated from each other for test purposes. Details of this brick wall construction and the adjacent wood-frame wall panels are shown in figure 3. All bricks were dark red. The brick wall was allowed to dry for several weeks before the wood panels were installed from the inside.

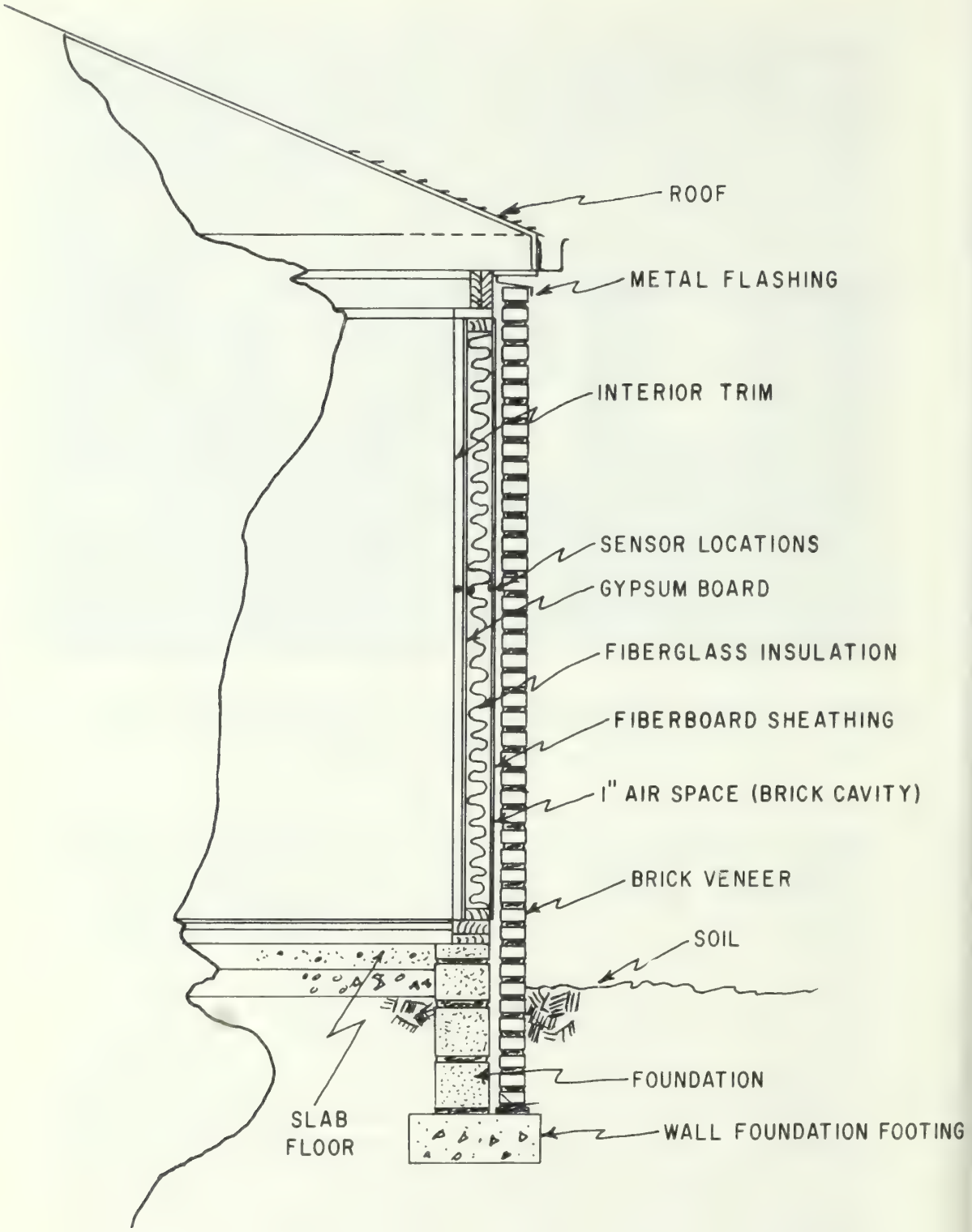

Figure 2.--A vertical cross-section view of the brick-veneered wall. Note the location of the wood-frame wall and the foundation details.

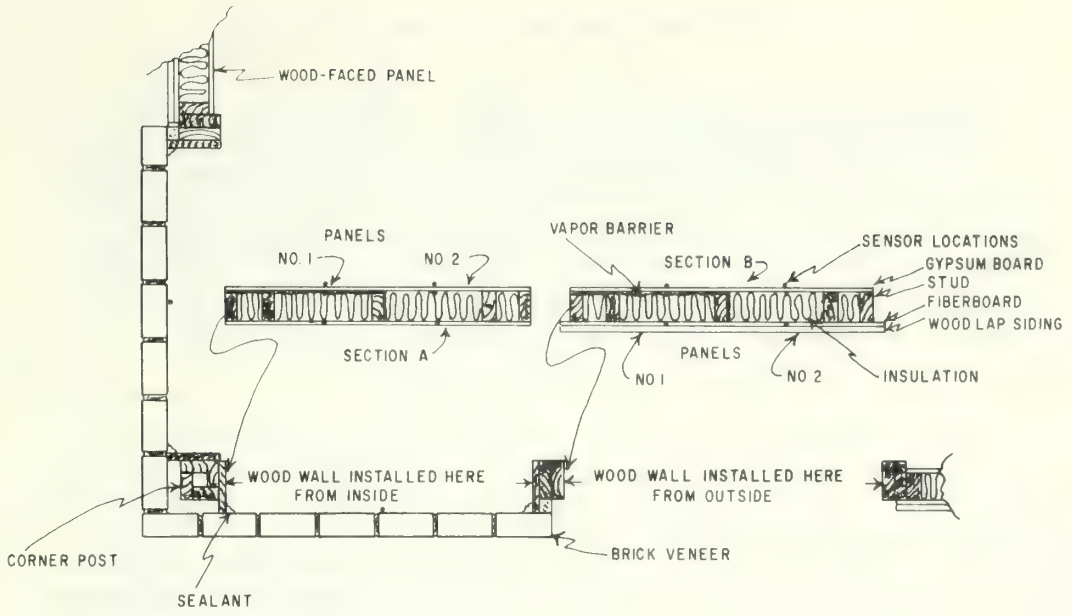

Figure 3. --A horizontal cross-section view of the brick-veneered wall section (A) and the wood-sided section (B).

Experimental Panels

Eight 4- by 8-foot wood-frame wall sections, each containing two 16-inch by 8-foot study panels, were used in the study. Each wall section consisted of five 2- by 4-inch studs positioned as shown in figure 3. The three center studs of the wall section were placed on 16-inch centers, with the the remaining side studs positioned to give a 4-foot width to the section. Each section was fabricated with an outer sheathing of 3/4-inch fiber insulation board and a 3-inch fiberglass batt insulation (without vapor barrier). A 0.006-inch polyethylene vapor barrier was positioned in study panel No. 1 on the interior face and stapled to the narrow face of the studs (fig. 3). Study panel No. 2 did not contain a vapor barrier. The interior of the wall section was covered with a 4 by 8 sheet of $\frac{1}{2}$-inch gypsum board and subsequently painted with two coats of latex white paint. The sheets of interior gypsum board and exterior sheathing board were continuous over the entire 4-foot width of each section. Two of the completed wall sections were installed at the northwest corner of the test structure and two at the southeast corner so that each section faced a different cardinal direction. These four wall sections were positioned behind the brick walls from the inside (fig. 3, Section A), and a 1-inch space was left between the inside surface of the brick veneer and the sheathing. Horizontal beveled wood siding was attached to the remaining four wall sections and painted with two coats of exterior latex paint. These wall sections were installed from the outside at the same time, as close to the brick-veneered walls as possible (fig. 3, Section B). Each wall section was sealed in place with a conventional caulking-type sealant.

Moisture and Temperature Measurement

Wood moisture probes were used to measure the moisture content at selected positions in the 16 study panels. These probes were made from small strips of hard maple (Acer saccharum Marsh.) cut to a dimension of 0.07 by 0.07 by 0.75 inch. The two tangential surfaces were coated with conductive silver paint. The moisture content of the wood probe was indirectly measured as a function of the electrical resistance of the wood between the two silver electrodes.[1] Each probe was calibrated to indicate the percentage of wood moisture content.

The temperature of each probe was monitored by a copper-constantan thermocouple adjacent to the probe. During the construction of the wall sections, the moisture and temperature sensors were installed in the geometric center of each wall panel (figures 2 and 3). Moisture probes and thermocouples were also installed in the geometric centers of the two outer wood studs of the two study panels in each wall section. Additional moisture and temperature sensors were located on the interior side of the brick veneer (in the cavity between the bricks and the wall sheathing) and on the exterior surface of the exterior sheathing. All sensors were at the midheight of the panels. All the lead wires from the sensors were extended to the top of the wall section for later connection to an automatic system where the data were collected and recorded on punched paper tape. No measurements of exterior climate were made in this study.

Experimental Procedure

During this study, the interior of the Whitehall test house was heated and air conditioned to maintain 75 ± 3° F. throughout the year with an electrical heat pump mounted in a window. During the winter heating period, the interior relative humidity was maintained at a constant level of 30 ± 5 percent with a floor-type humidifier. During the summer air-conditioning season, the interior relative humidity was not controlled, although the dehumidifying action of the air conditioning kept the relative humidity around 70 percent. The test house was not occupied during the course of the study except for occasional visits by research staff to collect data tapes. The structure does not contain any plumbing facilities to influence the interior moisture conditions.

Data collection was initiated in August 1968 and continued at 6-hour intervals during the 12-month study. The study was terminated in August 1969.

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[1]Duff, J. E. A probe for accurate determination of moisture content of wood products in use. For. Prod. Lab., U.S. For. Serv. Res. Note FPL-0142, 10 pp. 1966.

Data Analysis

Over one thousand readings were obtained from each moisture sensor used in this study. When all the observations were recorded on punched paper tape, the tape was processed and the data on moisture content were corrected for temperature and then plotted by a computer for visual analysis. Each month's data for a particular sensor were averaged into a single monthly value, which was subsequently plotted for final analysis.

RESULTS AND DISCUSSION

Moisture Conditions in the Dead-Air Cavity

Figure 4 shows the moisture conditions in the dead-air cavities of the north-, east-, south-, and west-facing brick-veneered wall sections. A comparison of the four time plots shows that the moisture conditions varied considerably during the 12-month study. The highest peak moisture condition was attained by the north-facing cavity (23 percent),[2] followed by the east-facing cavity (21 percent), and the south-facing cavity (20 percent). The west-facing air cavity attained the lowest peak moisture condition (17 percent). All peak moisture levels were attained during the months of December and January.

The differences in the peak moisture conditions can be related to the direction of exposure of the dark-red brick walls. Each cardinal direction of exposure receives varying amounts of solar radiation and wind. These two factors, when working independently or together, result in the drying of the brick veneer. Some venting of moisture-laden air was possible from these cavities around the edge of the metal flashing cap. Good external drying conditions for the brick veneer result in lower moisture accumulations within the adjacent air cavity. Hence, a large amount of drying would result in lower peak moisture levels in the cavity.

Brick walls that received the predominant effects of both solar radiation and wind would logically have reduced peak moisture levels in the cavity. Conversely, panels receiving little effect of these factors would have higher moisture levels in the cavity. The north-facing brick wall received less solar radiation than the other three exposures; hence, the expected peak moisture level in the cavity would be high, as shown. The south-facing brick panel would be expected to have a much lower level of moisture in the cavity because of the greater amount of exposure to solar radiation. Figure 4 clearly indicates this trend. It should be noted that the west-facing brick

[2] Percentages indicate wood equilibrium moisture content (EMC) of the air cavity, i.e., the moisture content attained under conditions of constant humidity and temperature.

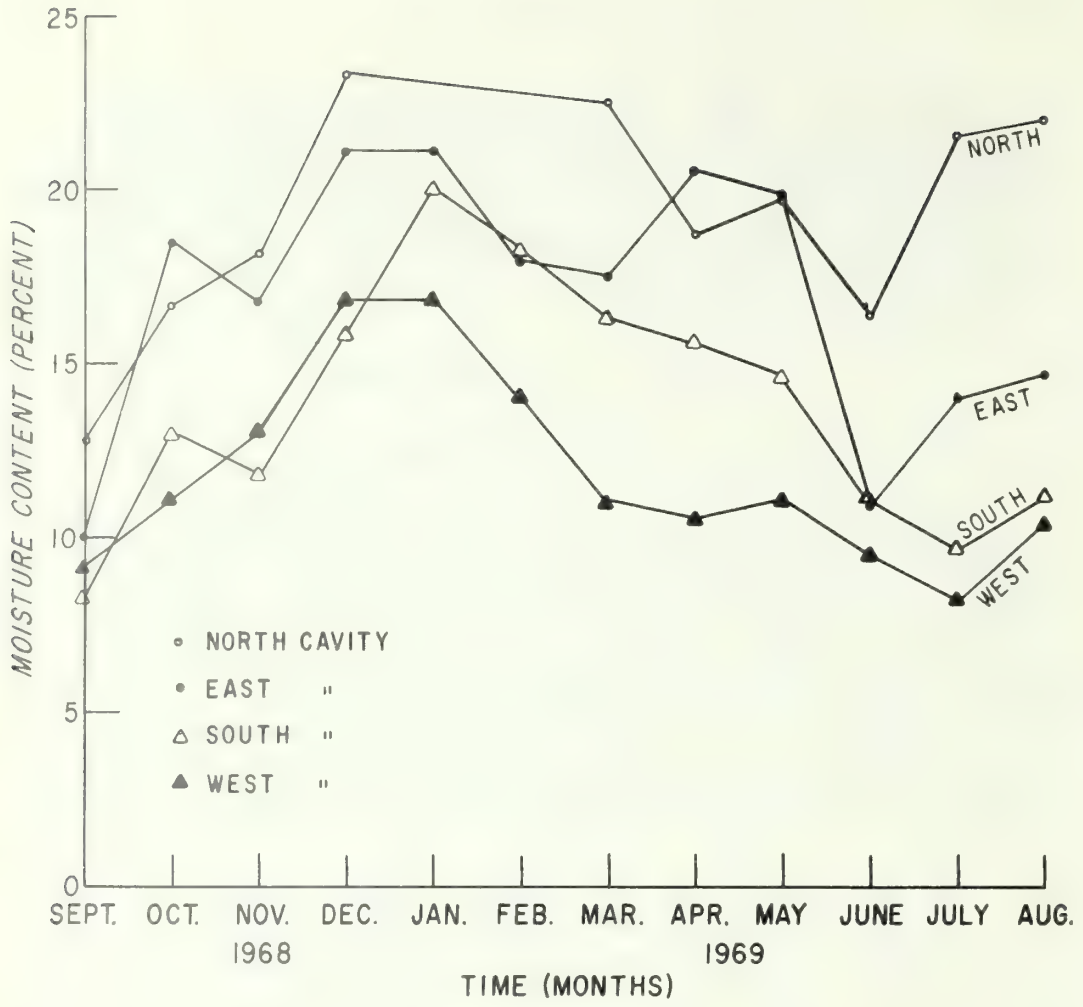

Figure 4.--Moisture conditions in the air cavities of the north-, east-, south-, and west-facing sections of the brick-veneered wall.

cavity had the lowest moisture level. The factor of wind must be considered in explaining this low moisture peak. The west-facing panel would receive large amounts of solar radiation during the afternoon; also, the effect of the wind would tend to increase drying conditions such that the moisture levels within the cavity would not be allowed to accumulate. According to the Athens Bureau of the National Weather Service (located 5 miles from the test house), the prevailing wind direction during the study period was westerly. Hence, during the study period, the cavity in the west-facing brick wall was probably more subject to the combined influence of the afternoon solar radiation and the prevailing wind than were the cavities in the other walls.

As the daylight hours increased from December until the summer months, the moisture levels in the cavities of the south- and west-facing panels dropped accordingly. The moisture level in the cavity of the

east-facing brick wall started to drop but increased again briefly, then decreased with the arrival of the warmer summer months when drying conditions were more favorable. The moisture levels in all of the cavities started to increase once the daylight hours started to shorten in early summer (June-July) when drying conditions were less favorable.

Effects of the Interior Vapor Barrier

Winter.--Figure 5 shows a typical time plot of the moisture conditions in the cavity between bricks and sheathing, in the exterior sheathing, and on the interior surface of the insulation for the brick-veneered wall facing east. This orientation was selected because of the greater variability in the moisture conditions in the air cavity. As expected, the moisture content of the sheathing followed the rise

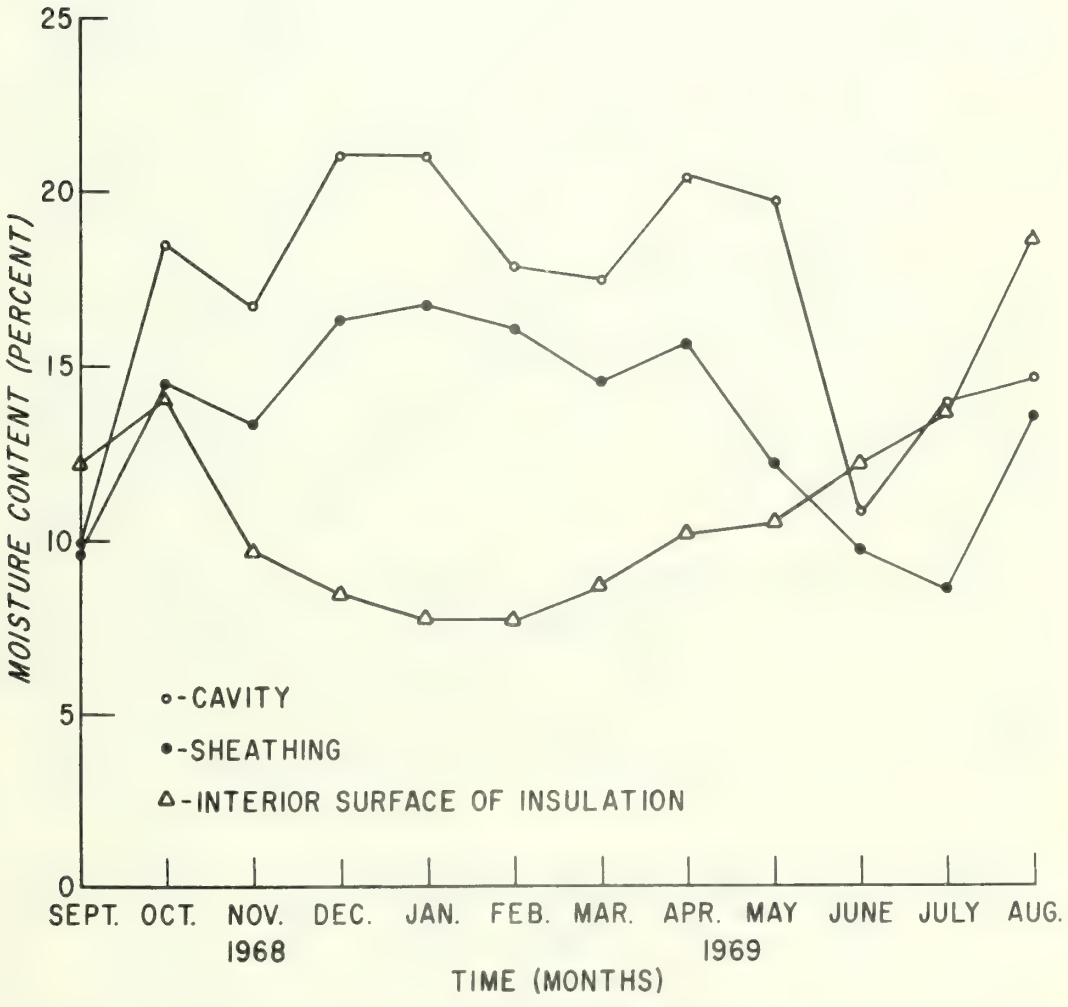

Figure 5.--A time plot of the moisture conditions in the east-facing wood-frame wall sided with brick veneer, with interior vapor barrier.

and fall of the moisture content of the cavity. The moisture peak of the sheathing (17 percent) coincided with the moisture peak in the air cavity (21 percent): both occurred in December to January. It is interesting to note that, although the sheathing surface was adjacent to the air cavity, the sheathing remained at a lower moisture level. This difference is partially explained by the fact that both surfaces of the fiberboard sheathing have a moisture-resistant material that prevents rapid moisture exchange. In addition, the EMC characteristics for fiberboard are lower than those for solid wood. For instance, tests of EMC of the fiberboard in comparison with moisture levels recorded by an embedded wood probe show the fiberboard to be 3 percent less in EMC than the 20-percent value recorded by the wood probe.

Figure 6 shows a time plot of moisture conditions in the exterior sheathing and on the interior surface of the insulation for the wood-sided wall facing east. A comparison of the moisture content of the sheathing for the brick-veneered wall and that for the wood-sided wall shows them to be somewhat different. The two sheathings peaked at the same moisture content (16 to 17 percent) but at different times (December to February for the brick-veneered wall and April for the

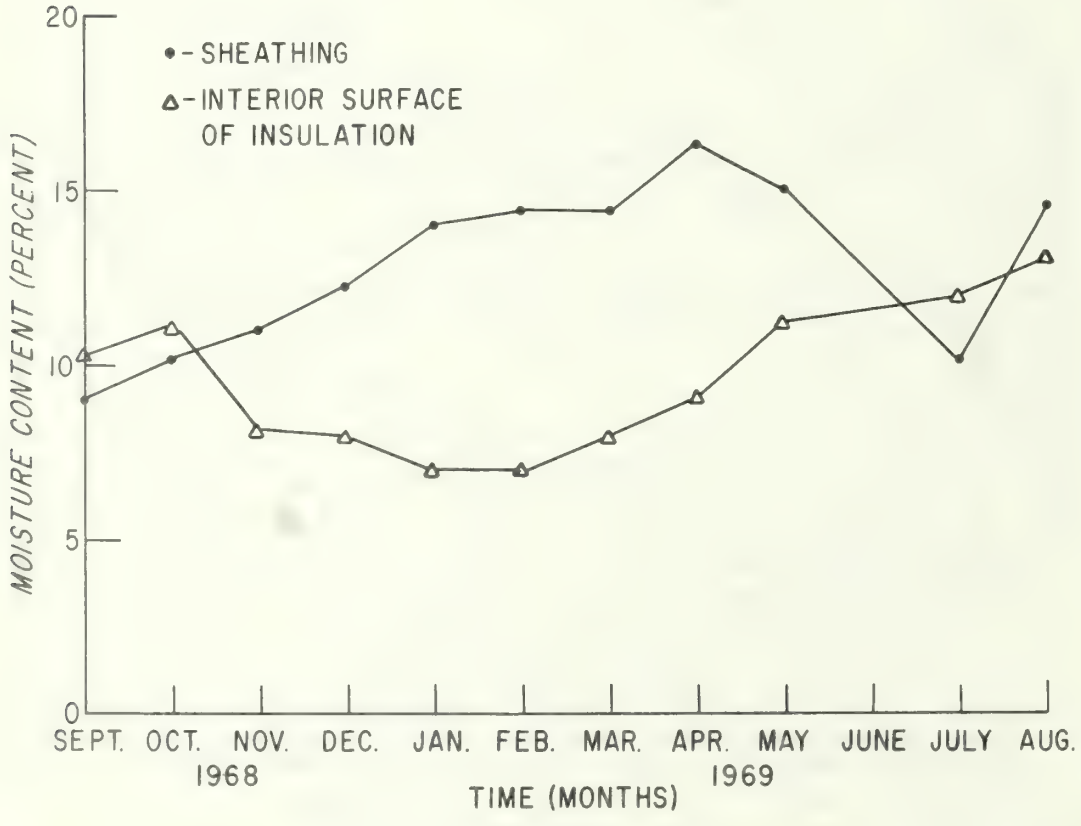

Figure 6.--A time plot of the moisture conditions in the east-facing wood-frame wall sided with wood, with interior vapor barrier.

wood-sided wall). The rapid rise in moisture content of the sheathing next to the brick in the fall was due to the high moisture level in the adjacent air cavity. The sheathing of the wood-sided wall did not have a high source of moisture available adjacent to its exterior surface. Hence, its moisture peak took longer to occur.

The similarity between the peak moisture levels in the two wall sheathings clearly indicates that the relatively high levels of moisture in the cavity did not result in excessive moisture penetration into the adjacent sheathing and insulation of the brick wall during winter. This lack of moisture penetration was probably due to the influence of a vapor pressure gradient that decreased across the brick wall section toward the exterior environment: moisture from the brick air cavity could not move against this overall vapor pressure gradient.

Summer. --Prior to this study, it was postulated that high moisture conditions in the cavity between bricks and sheathing during the summer could possibly cause excessive moisture conditions in the wall insulation, especially near the interior vapor barrier. Figure 5 shows a plot of the moisture conditions on the interior side of the insulation adjacent to the vapor barrier in the east-facing brick-veneered wall. The moisture level at this location decreased from a high of 14 percent in October to a low of under 8 percent in January. The moisture level then increased slowly to a maximum of 19 percent during August, when the study was terminated.

Figure 6 shows the plot of the moisture conditions at the same position in the wood-sided wall facing east. The same general trends of decreasing moisture level from a high of 11 percent in October to a low of 7 percent in January are evident. The moisture level then increased to a high of 13 percent in August. It is of interest to note that the peak moisture level of the interior surface of the insulation in the brick-veneered wall panel was 19 percent, whereas that in the wood-sided wall panel was only 13 percent.

When the study was terminated in August, the north-, south-, and west-facing brick wall panels all showed this same consistent trend of higher levels of moisture near the vapor barrier than were found at the corresponding positions in the wood-sided walls of the same orientation. These results suggest that the high levels of moisture in the air cavities were responsible for the higher-than-normal moisture conditions near the interior vapor barriers of all four brick-veneered walls during August.

Effects of No Vapor Barrier

Winter. --The time plot in figure 7 shows the moisture conditions in the air cavity, in the exterior sheathing, and on the interior surface of the insulation for the east-facing brick-veneered wall panel with no vapor barrier. Starting at a low of 9 percent in September, the moisture content of the sheathing increased to a peak of almost 19 percent

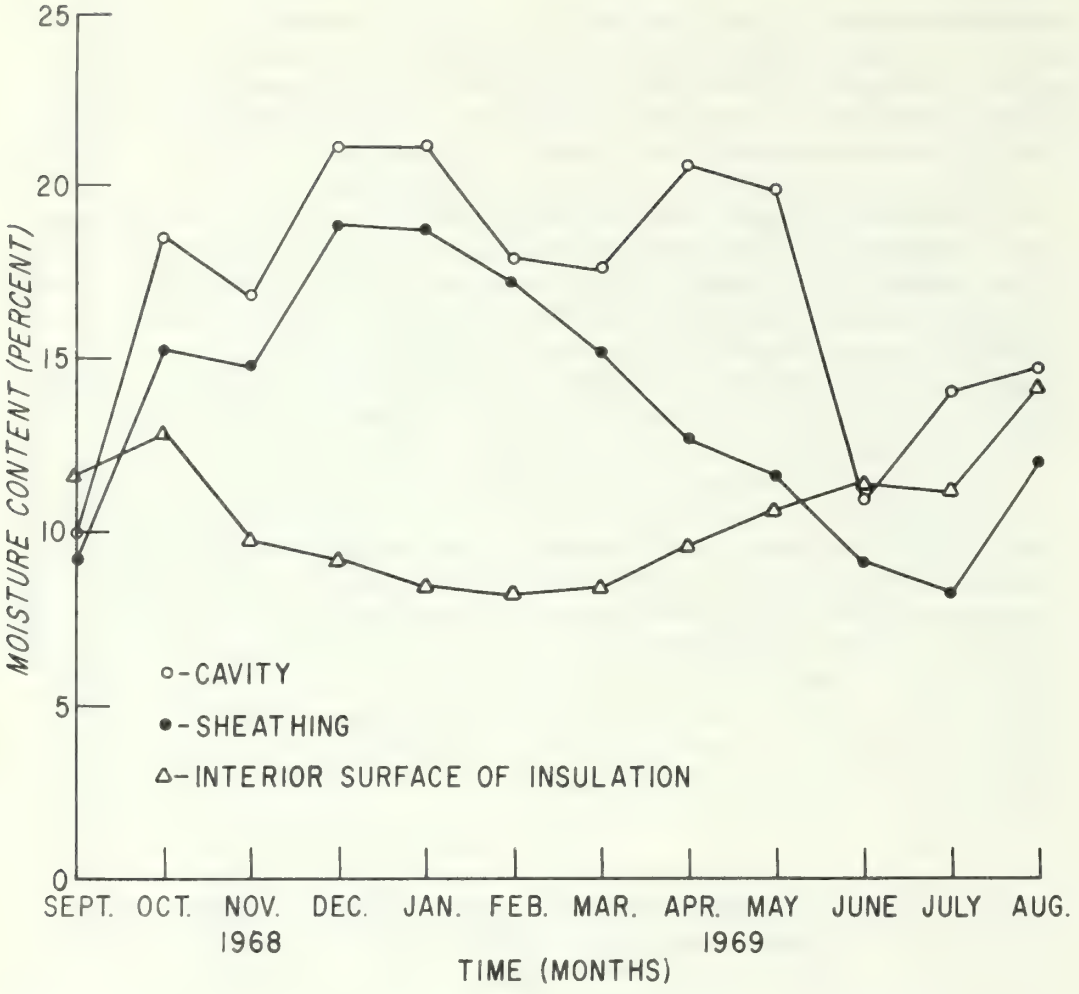

Figure 7.--A time plot of the moisture conditions in the east-facing wood-frame wall sided with brick veneer, with no vapor barrier.

in December and January. It is significant that this peak moisture content is only 2 percent higher than the peak moisture content for the sheathing with a vapor barrier (fig. 5). In colder climates, the moisture peak of the sheathing would be significantly higher when no vapor barrier is used.[3]

Figure 8 shows a plot of the moisture conditions in the sheathing and on the interior surface of the insulation of the east-facing wood-sided wall panel without a vapor barrier. A comparison of the moisture conditions in the sheathings of the wood-sided and brick-veneered walls without vapor barriers indicates a surprising difference (figures 7 and 8). The peak moisture content reached in the sheathing of the

[3]Duff, J. E. Moisture distribution in wood-frame walls in winter. For. Prod. J. 18(1): 60-64. 1968.

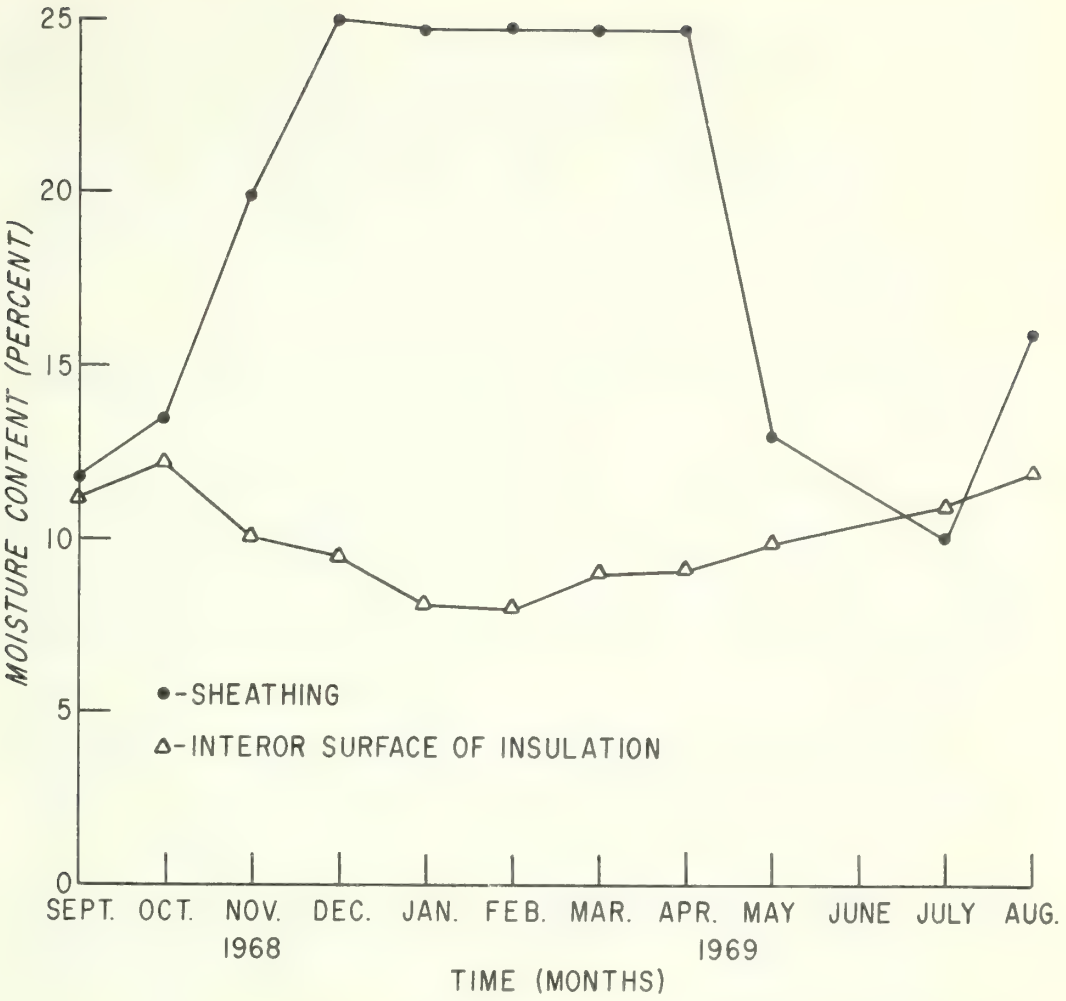

Figure 8.--A time plot of the moisture conditions in the east-facing wood-frame wall sided with wood, with no vapor barrier.

brick-veneered wall was only 19 percent, whereas the moisture content of the sheathing in the wood-sided wall peaked at 25 percent and remained at this level for 5 months.

This significant difference between the moisture levels of the two sheathings strongly suggests that the brick veneer either prevented a moisture buildup or reduced the moisture level in exterior sheathing when no vapor barrier was used. The brick veneer could prevent excessive moisture flow into the wall sheathing from the interior of the structure by altering the vapor pressure gradient across the wall. Normally, the vapor pressure gradient decreases toward the outside of the wall during winter. For example, the average vapor pressure for December inside the test structure was computed to be 0.260 inch of mercury on the basis of the average relative humidity and temperature of the interior air. At the same

time, the average vapor pressure outside the test structure was computed to be 0.197 inch on the basis of the average equilibrium moisture content and the average temperature of the exterior air. (Both vapor pressures were computed at a barometric pressure of 30.0 inches of mercury.) The steepness of this gradient determines the rate that moisture will flow through the wall. Essentially, the high level of moisture vapor in the air cavity of the brick-veneered wall (average vapor pressure of 0.268 inch in December) reduced the overall vapor pressure gradient across the insulated wall section to practically zero. This reduction in turn reduced the movement of moisture into the wall from the interior; thus, the sheathing was maintained at a lower moisture condition in the brick-veneered than in the wood-sided wall, even though no vapor barrier was present.

On the other hand, the wood-sided wall did not contain an exterior cavity with a high level of moisture vapor. Hence, the vapor pressure gradient established across its cross section from outside to inside was steeper. Thus, without a vapor barrier, substantial amounts of moisture penetrated the exterior sheathing from the inside of the structure and the moisture level of the sheathing was raised almost to the saturation point.

Another factor contributing to the differing moisture levels of the sheathings in the brick-veneered and wood-sided walls without vapor barriers was the different amounts of ventilation received by the sheathing surfaces. Although the cavity in the brick-veneered wall contained a high level of moisture during the winter, there was a certain amount of air exchange to and from the cavity through the brick veneer and the metal flashing joint at the roofline. Such air exchange would tend to prevent high levels of moisture from accumulating in the sheathing. The sheathing of the wood-sided wall was exposed to much less ventilation because of the proximity of the painted wood siding and exterior sheathing. Thus, moisture would accumulate to much higher levels in the wood-sided than in the brick-veneered wall.

The moisture contents of the sheathings in both the brick-veneered and wood-sided walls without vapor barriers decreased with the approach of warm weather. The moisture content of the sheathing in the wood-sided wall dropped abruptly in comparison with that in the brick-veneered wall. This abrupt drop in moisture level is indicative of a reversal of the vapor pressure gradient across the wall section. Both wall sheathings reached about the same low moisture content (8 to 10 percent) in July.

Summer.--Figure 7 shows a time plot of the moisture conditions on the interior surface of the insulation (against the gypsum board) of an east-facing brick-veneered wall without a vapor barrier. This location within the wall is particularly sensitive to any moisture accumulations which result from air-conditioning effects. The moisture level increased from a low of 8 percent in February to a high of

14 percent in August, when the study was terminated. A comparison of this peak with the maximum peak (19 percent) reached in the east-facing brick-veneered wall with a vapor barrier (fig. 5) suggests that the absence of a vapor barrier allowed much of the moisture that moved from the air cavity to pass through the wall into the interior of the structure, where it could be removed by dehumidification during air conditioning.

Moisture Content of Studs

The moisture content of the studs in the walls sided with brick veneer and wood was surprisingly constant (not plotted). The stud adjacent to the east-facing brick-veneered wall panel with the interior vapor barrier varied from 11 to 13 percent moisture content during the study. The stud in the brick wall panel without a vapor barrier had an identical variation in moisture content. The studs in the wood-sided wall section, with and without vapor barriers, ranged from 9 to 10 percent moisture content. It was interesting that, in the east-facing wood-sided wall section without a vapor barrier, the middle of the stud where the moisture sensor was located did not show the effect of the high moisture content in the sheathing (fig. 8). Obviously, the high moisture conditions were confined specifically to the outer region of the wall because of the vapor pressure gradient.

SUMMARY

In a year's study of the moisture conditions in typical, insulated wood-frame walls faced with conventional brick veneer and with wood siding in an air-conditioned and heated test building in Athens, Georgia, it was noted that:

1. The air cavity between the brick veneer and the wall sheathing in two of the test walls contained high levels of moisture in excess of 20 percent EMC during most of the year. However, these moisture levels did not cause any hazardous moisture conditions in any of the wood members of the adjacent insulated wood-frame wall.

2. The direction of exposure affected the peak moisture condition in the air cavity. It was noted that walls that were shielded from the wind and sun contained higher levels of moisture.

3. The 1-inch cavity between the brick veneer and the wall sheathing kept the moisture conditions in the insulated wood-frame wall with no interior vapor barrier below 20 percent during the winter months. These conditions were in distinct contrast with the consistently high moisture levels of approximately 25 percent that occurred in the wood-sided wall that contained no interior vapor barrier.

4. The presence or absence of an interior vapor barrier in the brick-veneered insulated wall made no significant difference in moisture levels within the wood-frame wall. For instance, in both types of brick-veneered wall the sheathing remained below 20 percent during the study. In contrast, the omission of the interior barrier in the wood-sided wall during winter resulted in severe moisture accumulations, as noted. However, wood-sided walls that contained the commonly recommended vapor barrier on the inside face of the wall remained dry during the winter period.

5. The moisture content of the studs in both the brick-veneered and wood-sided walls did not vary significantly (9 to 13 percent). Even though the wall sheathing in the wood-sided wall without a vapor barrier reached 25 percent during the winter, the adjacent stud supporting the sheathing was not affected. These results indicate that studs can be installed dry in insulated walls and can be expected to remain dry during use.

From the overall results of this study, it was concluded that the brick veneer in combination with the insulated wood-frame wall, either with or without an interior barrier, can be expected to perform well in mild climates like that found in Athens, Georgia. It is speculated that the wood-frame wall system with brick veneer could be made more effective in warmer and more humid climates than that found in Athens if the interior vapor barrier were omitted. Such a wall system would allow the moisture that tends to migrate into the wall during summer air conditioning to move freely through the wall without accumulating. Furthermore, the air cavity between the brick veneer and the wall sheathing would prevent any moisture accumulations during winter.

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Symptomatology and Spread of Fomes annosus in Southern Pine Plantations

by

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Symptomatology and Spread of Fomes annosus in Southern Pine Plantations

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In 1958, J. S. Boyce, Jr., then pathologist with the Southeastern Forest Experiment Station, established a number of small plots around naturally occurring infection centers in order to study the spread of Fomes annosus (Fr.) Karst. in thinned plantations of slash pine. These plots have been examined by the author periodically since 1962. In addition, several similar plots were subsequently established in thinned and unthinned plantations of slash and loblolly pines in order to study symptomatology and spread of the disease. This paper reports the observations made on these plots.

MATERIALS AND METHODS

Five plots, each 0.1 acre, were originally established by Boyce in South Carolina and Georgia. All trees in each plot were numbered and mapped. Pertinent information for these plots is shown in table 1. Approximately once each year, all trees in each plot were examined for the presence of symptoms and signs of the disease. Each tree was subjectively rated for degree of crown symptoms; yellowing and retention of needles and length of needles and internodes were noted in particular.

Living trees were considered to be infected if a conk was present. All dead trees were considered to have died from F. annosus if a conk was present; if none was present, the root system was excavated and examined for typical decay. In doubtful cases, roots were collected and returned to the laboratory for culturing.

Two additional plots in thinned plantations, each 0.25 acre, were established in 1962. One of these (T-1) was in a loblolly pine plantation near Chapel Hill, North Carolina, and the other (T-2) was in a slash pine plantation on the Sandhills State Forest in South Carolina. The latter plot was established with the help of Dr. Arthur Kelman and graduate students in forest pathology at North Carolina State University at Raleigh.

In 1963, three plots (UT-1, 2, 3) of variable size were established in order to include three infection centers in an unthinned slash pine plantation on the Sandhills State Forest. Similar data were taken on the additional plots.

Observations on the plot near Chapel Hill were continued until 1972. Observations on the remaining plots were suspended at various times because of losses by fire, ice storms, or inadvertent thinning.

Table 1.--Description of plots observed during study

Plot No.	Location	Date planted	Total trees	Date thinned	Spacing	Species
			No.		Ft.	
PE-2	Manning, S.C.	1940	26	1956	5 x 8	Slash
PE-3	Wedgefield, S.C.	1937	37	1952	6 x 6	Slash
PE-4	Cordele, Ga.	1940	17	1955	(1)	Slash
PE-5	Cordele, Ga.	1935	15	1954	15 x 15	Slash
PE-6	Wedgefield, S.C.	1939	37	1957	6 x 6	Slash
T-1	Chapel Hill, N.C.	1937	109	1957	8 x 8	Loblolly
T-2	Patrick, S.C.	1937	132	1954	6 x 6	Slash
UT-1	Patrick, S.C.	1950	202	(2)	6 x 8	Slash
UT-2	Patrick, S.C.	1950	152	(2)	6 x 8	Slash
UT-3	Patrick, S.C.	1950	181	(2)	6 x 8	Slash

[1]Variable spacing.
[2]Unthinned.

RESULTS AND DISCUSSION

Spread of the Fungus

The small size of the thinned plots and the fact that the disease was fairly evenly distributed within the plots at the time of establishment precluded any determination of the rate of spread. The data presented in table 2 represent only the intensification of the disease on a relatively small area. Therefore, they should not be taken as indications of losses that might be expected in entire plantations; the latter would be considerably less and would depend upon the number of such disease centers in the plantation.

Most of the trees became infected and died in the first 4 to 8 years after thinning. After that time, the disease essentially stabilized on all plots, and only an occasional newly infected tree was found. The planta-

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1974. Symptomatology and spread of Fomes annosus in southern pine plantations. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-114, 10 p.

The number of pines infected by Fomes annosus in a disease center increases for the first 4 to 8 years after thinning and decreases thereafter. On high-hazard sites, most infected trees die before they exhibit any progressive crown symptoms or conks. This tendency, coupled with the facts that only a few trees die in each center each year and that centers are usually scattered through the plantation, makes salvaging of the dead or infected trees difficult.

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